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The painting reproduced on the cover is an oil on canvas entitled "Konrad Oberhuber's Visit to Compass Harbor, Maine," by Michael Lewis, 1985. Lewis is Professor of Art at the University of Maine at Orono.

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From recognizing the potential for a new Maine business locked in the simple marine worm and working tirelessly to protect the lobster industry to finding ways to resolve Canadian/United States differences over the fish catch in the Gulf of Maine and bringing the lessons learned so dearly into Maine classrooms, marine studies at the University of Maine touch on every facet of the Gulf of Maine and its thousands of miles of coastline.

We have devoted our entire issue of EXPLORATIONS to marine studies, yet we have been able to touch on few of the projects directed to these issues.

Thanks are due the communicators and principal investigators who interrupted their busy schedules to write for us; the Center for Marine Studies, Darling Center, and Sea Grant staffs; Majo Keleshian who shared her artistic gifts; NASA and the York County Coast Star; the faculty and field crews who welcomed us into their laboratories and their field investigations.

Special thanks to Bob Steneck who, with professionalism and good humor, helped us extensively, and to Bob Whelan for his sterling advice and sound criticism.

Editor
The Gulf of Maine, a discrete sea within the North Atlantic Ocean, stretches from Nova Scotia to Cape Cod and is bounded to seaward by the Georges Bank. It serves as an abundant source of seafood, a promising source of energy from its massive tides and underground gas and oil deposits, and a recreational playground. It is also in grave danger.

The same technological prowess which makes it possible to fish the Gulf of Maine intensively, tap into its energy sources, and exploit it as a tourist attraction, gives man the ability and means to inflict lasting damage.

The Gulf of Maine:

A Sea Beside a Sea

by Kathleen Lignell

About 15,000 years ago, the retreating Ice Age glaciers left the North Atlantic a remarkable marine environment: the Gulf of Maine. A body of water 70 percent enclosed by New England and Canadian land masses, the Gulf of Maine is really a sea beside a sea.

As the ice sheet receded, meltwater etched river valleys like the Kennebec, the Merrimack, and the Androscoggin, while at the same time the ocean’s level gradually rose. The advancing sea filled in Penobscot and Casco Bays and flooded low-lying areas.

Over the next five thousand years, land surfaces relieved of the weight of the ice sheet slowly rose and the waters receded to a position approximating the coastal region much as we know it today. Encompassing 36,000 square miles from Cape Cod north and east to Nova Scotia and then south to Cape Sable, what was known by early European explorers as a rich fishing ground became the Gulf of Maine.

Today the Gulf is home for a complex ecological community: diverse open water species coexist with benthic (bottom) and pelagic (water column) species. The Gulf supports one of the most productive fisheries in the world, exploited by both commercial and sportfishing. It also provides an efficient water transportation system for shipping oil, gas, coal, and peat in large volume. Deep-water harbors comparable to those along the Maine coast are not found elsewhere along the eastern seaboard of the United States. In addition, the high tides and rivers of the Gulf provide an opportunity for tidal power and hydro-power development in a region with little or no natural gas resources. Finally, the Gulf of Maine offers the people who live along its shores a source of livelihood and recreation as well as an appreciation for its multiple riches.

_The Gulf is such a uniquely interesting body of water, _said Dr. George L. Jacobson, Jr., the botanist who heads the University of Maine’s Center for Marine Studies. _Research opportunities for University marine scientists are both exciting and important for the State of Maine. Not only is the Gulf of Maine system a logical natural unit for study, but almost everyone associated with the sea knows that we need to understand how that system functions in order to maintain the high productivity of these waters for years to come._

Dr. Les Watling, a biological oceanographer at the University’s Ira C. Darling Center Marine Laboratory, agrees with Jacobson's assessment. _One of the best things about doing research in the Gulf of Maine is it gives us the chance to get into a complex body of water and test new ideas and not be constrained by typical textbook examples of ecology._
Marine scientists, such as Watling, are currently emphasizing research in benthic oceanography at the Darling Center in Walpole, but the spectrum of research being conducted at the marine lab is diverse. Faculty from the University of Maine have access to these facilities to carry out research on polychaete biology, marine sedimentology, coastal geomorphology, beach dynamics, bivalve aquaculture, microbial ecology, estuarine chemistry, plankton ecology, marine paleontology, algal taxonomy, and crustacean taxonomy and ecology. The list is as vast as the Gulf itself.

The Darling Center, which is the University's window to the sea, is ideally located for coastal research in the center of the Gulf of Maine. Several unpolluted estuaries around the Damariscotta River estuary provide discrete, replicated systems about which questions concerning gradients in estuaries can be explored.

Much of the research carried out at both the Darling Center and the Orono Campus, particularly in the areas of soft-shell clam research, lobster ecology, oyster aquaculture, development of a sustained edible blue mussel industry in the Gulf of Maine, and the management of the tidal flat environment, has been supported by the Sea Grant College Program, a part of the Center for Marine Studies.

The University of Maine's Sea Grant College Program, in partnership with the University of New Hampshire, has pioneered in the integration of research, technology transfer, and education, all of which focus on the coastal and marine opportunities of the Gulf of Maine.

According to Dr. Larry Mayer, Acting Director of the University’s Sea Grant Program and Associate Professor of Geological Sciences and Marine Studies, There is growing interest throughout our state, indeed all of New England, in the Gulf of Maine as a single system whose health is critical to our quality of life. We have here an area of rapid population growth on a beautiful and productive body of water. Education and research are going to be critical components in making it all come together properly.

Mayer is a member of the scientific committee of the fledgling Association for Research on the Gulf of Maine, known as ARGO Maine. The instigation of this group was catalyzed by Dr. Arthur Johnson, President of UMO, and is headed by Mr. Harris (Pete) Bixler, of Northport. Last August, this coalition of Maine’s marine research organizations, including the private Bigelow Laboratory for Ocean Sciences, the Maine Department of Marine Resources, the Maine Geological Survey, and the University of Maine, convened for three days in Portland to share the current fund of scientific knowledge about the Gulf of Maine.

This meeting generated appreciable excitement among both the attending scientists and the news media. Mayer added, I think that the ideas generated by the scientists and the interest stimulated among all concerned will lead to some very high quality research in the future. Let’s certainly hope so. Meetings of this kind show us that, while we have made great strides forward in understanding the complexity of the Gulf, we still have a long way to go.

Because scientists lack a precise knowledge of the productivity of the Gulf of Maine, optimum management becomes impossible and stocks of commercially important fish and shellfish may be damaged.

Current Sea Grant-sponsored studies on bottom-feeding flatfishes in conjunction with the Maine Department of Marine Resources and the National Undersea Research Program will help lay the groundwork for new, multispecies fisheries management strategies in the Gulf of Maine.

Rich Langton of the Maine Department of Marine Resources is working with UMO’s Les Watling on an important study of the Gulf’s fisheries. The problem, they maintain, is for managers of such fisheries as lobsters, mackerel, and redfish, to determine what yield the Gulf’s ecosystem can bear. The danger, says Langton, is what happened to redfish a few years ago—a mismatch between biology and fishing effort. When landings peaked and capacity was exceeded, the fishery collapsed.

In an effort to increase the dwindling clam harvest in Maine, a UMO research team in conjunction with Maine’s Advisory Service responded to an appeal from local clam diggers, town clam committees, wholesalers, and clam wardens in coastal communities. Over a decade of Sea Grant Research on basic clam biology, clam seed-planting efforts in coastal towns, and the economic impact of clam flat management have only recently begun to generate information needed for the improved productivity of the soft-shell clam resource, Maine’s third most important commercial fishery, after lobsters and groundfish.

In 1979 a Sea Grant research program, known as the Clam Project was initiated, consisting of a team of a sedi-
mentologist, a biologist, a geochemist, and an aquaculturist. While a study of soft-shell clams and their mud flat environment was carried out in Jonesboro during 1980-81, the aquaculture facility at the Darling Center was the site of hatchery-rearing activities for spawning clam broodstock. After spawning, the clams were shipped to nursery sites in various coastal towns up and down the state.

Meanwhile, Sea Grant researchers were also studying the biology of the clam through feeding and growth experiments, while sedimentologists were conducting field and lab experiments to determine the grain size characteristics and nutritional quality of the clam flats.

Already clam diggers in Freeport, Jonesboro, and four other communities have begun to harvest clams spawned four years ago in the Darling Center hatchery. In Brunswick, an inexpensive new clam seed dredge, developed by John Riley of UMO's Agricultural Engineering Department with Sea Grant support, now makes it possible to transplant natural clam seed from overcrowded areas to areas depleted by the elements of man.

Along with a recent Sea Grant publication compiling a decade of research results, Increasing Clam Harvests in Maine, the development of aquaculture techniques, the mechanical seed harvester, and an innovative 4-H program in raising clams from a hatchery built and maintained by the youths themselves will assist all coastal towns to manage their clam harvesting for optimal production.

Better knowledge of the Gulf of Maine, researchers concede, is the key to protecting it against shortsighted decisions. Although the Gulf is still one of the most productive marine environments in the world, threats do exist to its near-pristine quality: the growing population along its various coasts; degradation by heavy metals, PCB's and airborne pollutants from hydrocarbons; the threat of oil spills, and overharvesting of its fishery resources.

On the brighter side, marine zoologist Dr. Robert Steneck of the Darling Center tells us why the Gulf is so productive. A combination of sunlight, water, and nutrients at certain depths means excess energy production, which feeds less productive areas, he comments.

Standing before a satellite-image of the Gulf of Maine, Steneck points out the details in the photograph taken from space. The warm water of the Gulf Stream appears yellow; the cooler water inside Georges Bank is green; the cold water of the Bay of Fundy is blue. Like a child's kaleidoscope, the three swirling colors appear to be moving in a circle, propelled by currents. See page 11.

Relayed by NASA's Nimbus-7 satellite from high above the Gulf of Maine, these photos reveal a counterclockwise gyre that moves water, nutrients, and marine life around the interior of the Gulf. This circulation is propelled in part by warm, salty water entering from the Atlantic Ocean through a wedge in the banks, the Northeast Channel. Spring river runoff of snow melt, cold ocean water from the Scotian shelf off Nova Scotia, and winds and tides all contribute to the internal circulation in the Gulf.

Satellite imagery also shows that the areas of highest biological production occur usually where water movement is strongest—along the coast and over Georges Bank.

Dr. Bryan Pearce of UMO's Department of Engineering is developing a circulation and tidal response numerical model in the Bay of Fundy/Gulf of Maine. This model will significantly improve our understanding of the system itself.

Pearce and his associates have already contributed to our knowledge about the physical processes of Penobsct Bay. The Penobsct currently supports economically important fisheries and tourist industries and is considered by many as a suitable region for new industrial and port development. By modeling the data Pearce's research team has gathered, they can eventually predict the transport of pollutants, marine organisms, and sediments within this estuarine environment.

Modeling is a tool which divides the bay into separate or discrete elements. Various forcing functions such as wind or tide are applied to each element forming an equation for each element. The system is then solved to find the water velocities. This can be done for any time period. The results show the effects of wind, tide, current, and river discharge on the total water movement. The model is tuned so that it agrees with what is happening in areas where data exist. It is then applied to areas where there is no data.

Pearce is confident that the modeling process will produce a better picture of long-term transport in the test estuary. This information can then be used to direct planners to estuaries which are least vulnerable to commercial and industrial development.

Until recently people have used the Gulf of Maine as they have seen fit, without much thought for the consequences. Conflicts over the use of the resources of the Gulf and its coastlines have grown in recent years. Commercial fishing, electrical power generation, residential housing development, agriculture, recreation, manufacturing, and commercial business all play an important role in the utilization of the region's resources. If we wish to continue to depend on the Gulf for its fish, lobsters, and clams and to attract tourists to its coasts, we will have to expand our knowledge to protect it from overexploitation. At this point, we have everything to gain, and nothing to lose. And UMO researchers are in the forefront of those seeking to understand the bountiful productivity of the Gulf of Maine.
The inexorable pull of the sea: cradle of life, provider of bounty; soothing and gentle, yet massive and deadly, the oceans of the world have attracted man since his misty beginnings. Ulysses braved the numbing call of the sirens; Hemingway's old man guarded his catch against the overwhelming odds of predators and tides; frenetic Vikings sailed rough seas in frail ships to loot and plunder; watermen learned the intricate expanses of fishing grounds and built entire economies, even societies, upon their rich plenty. While all oceans harbor some life forms, five maritime areas on earth are outrageously rich and productive: the seas off Japan, the west coast of South America, parts of West Africa, parts of Northern Europe . . . and the Gulf of Maine.

THE GULF OF
world of promise

by Carole J. Bombard
for David Sanger

The Gulf of Maine, a discrete sea within the North Atlantic, has served as an essential resource to man for thousands of years. Scoured and molded by the glacial might of the Laurentian Ice Sheet, its coastlines have changed as the land bent to the ice and then rebounded when released from its iron fist.

As it has evolved over the past few thousand years, so have its tidal mixes changed, and along with them, its nutrient balances and temperatures. And all of these factors have determined the life forms it can support. By extension, part of what the Gulf of Maine has supported throughout this time is man.

Environment inevitably has a strong effect on human societies and cultures. While no society exploits all of the raw materials available to it and while it may well import, even in a most primitive fashion, some raw materials, the less technologically sophisticated a society, the stronger the influence of the ambient environment.

How did ancient humans adapt to the changing environments of the Gulf of Maine littoral? How did prehistoric cultures evolve in response to the changing carrying capacity of the Gulf?

How can we know? What information will be relevant to satisfy our questions? What mechanism can we use to protect the cogency of our conclusions?

We hypothesize. We begin with suppositions based on what we do know and which we may use as general models to generate information and new knowledge.
David Sanger received his B.A. degree from the University of New Brunswick; an M.S. from the University of British Columbia, and a Ph.D. from the University of Washington. He joined the UMO faculty after six years with the National Museum of Man, Ottawa. He is currently Professor of Anthropology and Quaternary Studies. Sanger’s research interests include the prehistoric archaeology of the northeastern United States and Canada and the adaptation of prehistoric hunters and gatherers to maritime environments. He has published on his research in western North America, the Arctic and Scandinavia.

MAINE LITTORAL

An hypothesis is an unproven theory or proposition which is tentatively accepted to explain certain facts or provide a basis for further investigation. There are good hypotheses and poor hypotheses.

A sound hypothesis combines correspondence and coherence theories of truth: it must on the one hand insure that the things we say (signs) correspond to things in the real world (objects); it must also insure that the things we say (signs) are compatible or noncontradictory with other things we say (signs). When an hypothesis combines both sign-object and sign-sign agreement, it satisfies the better requirements of truth theory.

But an hypothesis must be more. It must be narrow enough to be relevant, to pertain to a phenomenon; yet it must be wide enough to provide a useable generalization from which we may infer and learn if we are to expand our understanding. And it must have a built-in mechanism through which unwarranted conclusions may be demonstrated false; without such a mechanism, all propositions are true and the hypothesis is meaningless.

David Sanger, Professor of Anthropology and Quaternary Studies at the University of Maine at Orono, has worked for years studying the more than 2,000 prehistoric coastal sites of human occupation along the Gulf of Maine littoral. Sanger is keenly aware of the caution necessary when working with an hypothesis. Little, he says, can be gained through analyses that attempt to interface broadly conceived abstractions such as culture and climate.

The Gulf of Maine Adaptive Model comes under close scrutiny from Sanger. It predicts that the development of culture in the Gulf of Maine littoral is functionally linked with the evolving physical and biological oceanography of the Gulf. Sanger argues that while it is possible to hypothesize cultural adaptation to models of oceanographic change, it is necessary to document in detail both the natural and cultural systems that are thought to be functionally related. People do not adapt to models no matter how elaborate they are: people adapt to field conditions.

PEOPLE ARE NOT CLAMS
ALTHOUGH THEY ATE THEM
AD NAUSEUM

In addition to insuring the general validity of any conclusions drawn from a model or hypothesis, Sanger demands documentation because of the quality of human choice. Human beings are flexible and exhibit an appreciable amount of variation in their selection of where they will make their settlement; the type of subsistence pattern they will follow, and the seasons during which they will occupy certain areas. People simply are not spineless clams, although they ate them ad nauseum.

Adaptive behavior may be demonstrated by two case studies from the central coast region of Maine: A sea level rise that created an ideal environment for a relatively short-lived colonization by the American oyster, its exploitation by Native Americans, and its subsequent demise, and a sea level rise that caused changes in water temperature and substrate resulting shifts in shellfish species collection and site location. These examples have been studied in detail.
In both of these cases, sea level changes were the predominant force in human adaptation changes; sea level rise determined the kind and amount of littoral available for use by humans and sea level change affected the tidal range within the Gulf of Maine. Tidal range, of course, determines nutrient mix, interaction with the sunlight, the extent of plankton bloom, temperatures, and the biomass which the Gulf can produce. Immediately dependent upon the biomass are the energy and life forms carried in the Gulf.

Fossil remains from the Gulf indicate that a cooling of surface temperatures during the past 4,000 years has resulted in changes from the smallest foraminifera types to the loss of swordfish in the Gulf. In addition, the remains of oysters and quahogs in places such as the Damariscotta River shore, combined with the fact that there are no such living beds nearby, is clearly indicative of environmental change. In this case, it is most probable that summer water temperatures dropped below the minimum required for spawning.

**OYSTER SHELL HEAPS**

The Damariscotta Oyster Shell Heap project is an example of research into the causes of cultural variability. The size and the makeup of a number of large, oyster shell middens on both banks of the Damariscotta River above the towns of Damariscotta and Newcastle have fascinated naturalists because oysters no longer grow in the river; the size of the oysters greatly exceeded those from other rivers (some of the oyster shells measured 14 inches: 35 cm), and the shell middens downstream in the Damariscotta River (and elsewhere along the Maine coast) were made up mostly of soft-shell clams and were appreciably smaller.

A clue to the age of the oyster shell heaps, and simultaneously to the history of sea level rise, was built into the river. A series of bedrock and boulder sills in the Damariscotta River had to be breached by the rising tides and sea level increased before the area of the shell heaps could be adequately saline to support oysters. One of the last barriers to upstream migrating of the tides is known locally as Johnny Orr, and until salt water flooded over Johnny Orr, oysters could not live in that stretch of the river where their huge shell heaps are found. Eventually some radiocarbon dating produced dates of about 2,300 for the shell middens. They were abandoned several centuries before the arrival of Europeans in the area.

Why did the oysters die out in the river? Several hypotheses have been advanced to explain their disappearance:
- during the 18th and 19th centuries, forest clearing and soil runoff in conjunction with agriculture contributed a great deal of sediment to the river; the sediments accumulated rapidly and smothered the oyster beds.
- sawmills and their related sawdust acted to smother the oyster beds.
- as the Johnny Orr sill was inundated, the cold sea water reduced the summer water temperature below what was required for spawning.

The smothering hypotheses are most probably false: it is highly likely that the Native Americans left the area when the oysters became extinct; that date would have been several hundred years prior to the arrival of Europeans with their sawmills and agricultural systems.

Carter Newell, a biological oceanographer who earned his M.S. degree at UMO, was recruited to provide background on oyster ecology. He developed a habitat suitability index for oysters, and it included the factors relevant to their survival: bottom conditions, mean summer water salinity, percent of bottom covered with oysters, prevalent annual water salinity, mean interval killing floods, mean substrate firmness, mean predator abundance and mean disease intensity.

All of these boundary conditions are favorable for oyster habitat in the Damariscotta River under current conditions except for the predator load. Oysters can colonize water with salinity as low as six parts per thousand, and ranges from 10-30 parts per thousand are acceptable; currently salinity above Johnny Orr ranges from 15 parts per thousand in the spring to 29 parts per thousand in the summer and fall. But recent attempts to reintroduce oysters into the river have failed because of an abundance of predators, especially the oyster drill. Because oyster drills cannot survive salinity levels of less than 20 parts per thousand, it is suggested that the predator load, and the salinity levels determining it, may have been lower in the past.

1985 excavation of a shell midden site on Great Spruce Island.
The currently available facts support the following explanation of oyster presence and intensive human exploitation, according to Sanger: Oysters were once widely distributed throughout the Gulf of Maine as one of the warm water species. As temperatures declined, the oysters were restricted to warmer estuaries where shallow water developed higher summer temperatures and freshwater inflow created brackish conditions. As sea levels rose, new colonizing areas became available in the upper portions of the estuaries until oysters in the mid Maine coast region were in isolated, or disjunct, relic populations. The Damariscotta was one of these estuaries.

By 2,500 years ago, sea level had risen over Johnny Orr creating a brackish environment suitable for oyster spat colonization. Initially, the traditional predators and competitors were incapable of following due to low salinity.

Shortly after this time, oysters established large colonies and grew to the huge sizes recorded in the shell middens. Native Americans, who had been involved with shellfish procurement for several thousand years previously, took advantage of the shallow oyster beds and collected them in great quantities.

Collections of remains indicate that the Native Americans were not adapting to a single food source however. Deer and other terrestrial mammals, fish and birds are all well represented by remains in the shell middens. It appears that the profuse oysters focused attention on that area and affected settlement patterns.

The boom lasted until about 700 years ago when sea level rose sufficiently to allow enough salt water to create salinities of 20 parts per thousand and above, the point at which the predator load greatly increases. After that time, the predators put such a heavy load on the oysters that the Indians found it advantageous to move on to more productive gathering areas: they may have moved to the lower reaches of the Damariscotta River.

In summary, if this reconstruction is correct, it provides an example of a relatively short-term adaptation to an environment that was created by a mid-Holocene event, the rise in sea level.

The reconstruction outlines the way in which the oyster population was adapted to and used by Native American populations, but it is not safe to assume that by dating the time of Native American adaptation, the breaching of Johnny Orr by salt water has been properly dated.

In a typically UMO interdisciplinary fashion, a geologist and an ecologist, Davida Kellogg and Dan Belknap, were drawn into the study to provide additional data.

Core samples were taken from the river close by the archaeological sites: it was hoped that the cores would contain datable diatoms indicating the time of change from fresh water to salt water. First attempts failed, but subsequent sediment cores have been taken and their contents are in the process of laboratory study. They may well provide an independently dated chronology to support or possibly modify the archaeological site chronology.

**MUSCONGUS BAY PROJECT**

Between 1979 and 1982, archaeological surveys located more than 200 coastal sites within the Boothbay region, and 10 percent of the sites were tested to various degrees. The region offered potential as a locality which could be used to develop an in-depth examination of the man to sea relationship.

The sites also looked promising as a concrete opportunity to test some of the hypotheses developing out of the general adaptive model of prehistoric cultures evolving in response to the changing carrying capacity of the Gulf of Maine.

In 1983, Dr. Sanger and graduate student Douglas Kellogg began site surveys in Muscongus Bay, just east of the Boothbay region. Kellogg sampled 25 percent of the 762 kilometers (475 miles) of shoreline using a stratified, random sampling strategy, and, as the sites were tested, the potential of the northwestern part of Muscongus Bay to support an interdisciplinary examination became evident.

A particularly sterling possibility for interdisciplinary study took the form of the Todd site; beginning with a Susquehanna occupation, the site has experienced almost 4,000 years of occupation. The Todd site shell midden's lower levels are dominated by quahogs, and more recent levels are comprised of soft-shell clams and blue mussels; radiocarbon dates indicate that the shell midden accumulation began about 2,200 years ago.

The change from quahog to soft-shell clam and blue mussel indicates a change in the local environment because quahogs are not found nearby in any appreciable numbers and quahogs require warmer summer water temperatures for spawning. Reconstruction of the paleo land surfaces and the effects on water circulation patterns indicates just how this could have occurred.

Across a narrow channel from the Todd site is Hog Island, with a large shell midden containing no appreciable quahog remains. A shallow thoroughfare separates Hog Island from Loud's Island which has a number of soft-shell clam middens. Currently, even a small encampment could not be supported for any length of time by the available clams. But clues visible to the archaeologist's eyes indicate that this was not always the case.

Unconsolidated sediments are found at the ends of both islands, and it seems highly likely that at some time in the past they were joined. That particular geographic arrangement would have provided an extensive mud flat well suited to shellfish gathering.

There are any number of unsubstantiated clues pointing to shifts in the nature of the local ecosystems during the time humans occupied the Muscongus Bay area. Their abundance prompted research into the precise nature of these changes.
During the 1984 field season, Belknap used 45 km (28 miles) of seismic profiles to map the depth to bedrock and the thickness of Holocene and Pleistocene sediments. Seven vibrocores up to nine meters (9.75 yards) were taken to confirm the seismic interpretations and directly sample sedimentary units.

Douglas Kellogg, a candidate for the Individualized PhD degree, is analyzing the results for his PhD. Preliminary results indicate that what is an open, high-energy shoreline today, was a broad tidal flat between Hog and Louds Islands about 2,000 years ago. In a similar fashion, it appears that the thoroughfare between Hog Island and Hockomock Point was quite constricted, with broad flats in Greenland Cove and Hockomock Channel. It is entirely probable that tidal scour during rising sea level during the last 5 to 2,000 years opened the narrows. As the thoroughfare between Hockomock Point and Hog Island was established, tidal flow and currents were altered, and they would in turn cause a greater tidal exchange of water in Muscongus Bay. The increased amount of colder, tidally mixed water would have been detrimental to the quahog populations but favorable to the soft-shell clams and blue mussels, the dominant species found in the area today.

The area is still under active study. A vibrocore has been taken in a millpond which once supported a tidally driven mill; it indicates the point at which fresh water was overcome with salt water. Samples from the core have been taken for diatom analysis and may possibly indicate the first overtopping of the sill during sea level rise. As the study continues, attention will be paid to integrating the cultural response of humans to the plants on land, the geological and sea level data, and the record of plants and animals in the sea.

**ROQUE ISLAND GROUP: AN INFANT STUDY**

A natural harbor and a long crescent sand beach are enclosed by the Roque Island group just east of Jonesport in Washington County, Maine. In 1978, a crew of four, under the sponsorship of the Maine Historic Preservation Commission, surveyed for sites in and around the many islands in the area. Many sites were found. The islands were revisited in 1982 with the express purpose of testing the sites discovered during the initial field season.

Nature won over the archaeologists: her nasty fogs, winds and rain kept the investigations to a minimum. With nature at her nastiest, the team was restricted to the Great Spruce Island site where they managed to unearth deep shell deposits overlain by massive quantities of peat; debitage from toolmaking; fish and mammal remains; pot sherds and a house pit. The daunting aspect to the investigation was the extensive unorganized digging which had been done by amateurs.

Test pits turned up shell deposits in at least two distinctive layers, and the crew began looking for house pits. A trench was dug into the woods behind the shell midden, and soon the evidence of a house began to appear: shell free, charcoal-stained gravel, low bone counts, high artifact yields, especially stone flaking debitage and artifacts broken in manufacture. While it was impossible to excavate the complete house floor, enough was done to reveal a double row of rocks forming at least one side of the house, and educated estimates put the house at about 2.5 meters (8 feet) across. Dense debitage and broken bifaces were concentrated at the edge of the house, as if to remove the sharp fragments from the floor of the living area. Radiocarbon dating of samples by the Smithsonian Institution Laboratory suggested a date of about 1,100 years ago for habitation of the house.

An area of investigation rich in data was the identification of the species of animal, fish and fowl exploited by humans from the remains dumped near the house: clams and other shellfish made up a huge proportion of the remains; also identified as heavily exploited were bottom fish such as tom cod and sculpins; sea mink and seals represented marine resources, and deer and assorted small mammals were obviously taken from the land. Larger rodents were represented in small quantities, as was a moose.

The larger number of scaup (duck) remains as well as the types of fish remains (tom cod) indicate that the camp was probably occupied in winter. Remaining to be done is the sectioning of some of the shells and shell fragments: as with tree rings and tree fingerpints, clues to the climate and general environment can be determined from shell rings.

The summer of 1985 saw a return to the Roque Island group with far better weather and consequent archaeological finds. Those extensive remains have been properly identified and recorded in situ, bagged and shipped to the laboratory, where they will undergo extensive study in the process of determining the adaptations which ancient humans made to the rich biota of the sea and land along the Gulf of Maine littoral. Man has always adapted to his environment: the plethora of rich resources produced by the Gulf of Maine produced one of the rare occasions when man turned away from many of the resources of the land which paled beside the outrageous bounty of the sea. See photo page 11.
NASA satellite photo of the Gulf of Maine.

Roque Island crescent beach and the dig opening.
MARINE WORMS WORTH FIFTEEN DOLLARS EACH?

by David Dean

Yes, that's right, fifteen dollars each—if they can be obtained when needed, in the right size, and in good condition. At this price, they are obviously not used for fish bait, like their sandworm and bloodworm relatives. Their scientific name is *Myxicola infundibulum* and they are members of the fanworm family *Sabellidae*.

What makes this species so valuable is that, instead of a spinal cord as we know it, each worm contains a single, exceptionally large nerve cell, called a giant axon, that extends almost the entire length of the worm. In general, the larger the worm the larger the axon. Axons are reported to attain 1.5 mm in diameter in the largest specimens. These cells then vie for the title of being the largest cell in the animal kingdom. Another close contender for the title is the giant axon of the squid. Squid, however, cannot be shipped alive, and scientists who wish to use squid for neurobiological studies must pack up their sophisticated equipment and transport it to a seaside laboratory where squid can be maintained. It is from studies using giant axons that such of our basic knowledge about nerve properties and their structure and function has been obtained.

In the mid 1960s, *Myxicola* was discovered to be as useful as squid for neurobiological studies. *Myxicola* could, however, be shipped easily to inland laboratories and maintained satisfactorily in seawater aquaria for two or three months. As the number of scientists using *Myxicola* in their research increased, the demand for the worms began to exceed their availability. Up to this time, the supply of *Myxicola* depended upon SCUBA divers collecting specimens by hand from natural populations. The obvious answer to guarantee a ready supply of the worms when needed was to raise them. This is where the University of Maine at Orono entered the scene.

At UMO's marine laboratory, the Ira C. Darling Center for Research, Teaching and Service in Walpole, an Aquaculture Building had been designed and built in 1971-72 specifically for raising all types of marine organisms. More than 17 species of molluscs, crustaceans, fish, and worms have been raised there, many for the first time. Having this exceptional facility and experienced staff available was instrumental in convincing the National Institute of Health to award a three-year grant exceeding $225,000 to Prof. David Dean of the Department of Zoology and the Darling Center to develop the technology to culture this species.

In the last twenty years, as *Myxicola* became an increasingly valuable research tool, primarily in medical schools and cancer foundations, practically no attention was given to understanding the biology and ecology of the worm itself. Thus, before actual culture work could begin, much background information had to be obtained about the species itself.

The natural habitat of *Myxicola* is below the low water mark in rock crevices or between horse mussels that grow in clumps. They are much less common in sediment. They are cold water forms and, along the Atlantic seaboard of North America, are found from New Brunswick, Canada, in shallow depths to the deep waters of Delaware. The worms are best collected by hand while using SCUBA gear. The worms are fragile and secrete a thick, viscous, jelly-like tube between their soft bodies and their environment (rock, mussels, etc.) to help protect themselves from abrasion and their enemies. Their main defensive mechanism, however, is almost instantaneous withdrawal into their tube at the slightest indication of danger. This rapid withdrawal results from an impulse traveling the length of the giant axon almost simultaneously, with each body segment receiving the message to contract at almost the same time.

Research on the laboratory culture of *Myxicola* has been many faceted and has included ways to maintain adults, larvae and juveniles; diets; growth rates; spawning stimuli; larval development; temperature optima; and regeneration. Significant progress has been made on all subprojects. It appears as if the long-term goal of providing technical skills to the public and to commercial aquaculturists so they may raise these worms for scientific research is attainable in the near future.

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The Canadian/United States boundary in the Gulf of Maine, as recently set down by the International Court, has caused some unhappiness and concern in the fisheries industry. But there is an answer, one which will bridge the troubled waters and bring health to the fisheries on both sides of the border.

**FREE TRADE, NOT TRADE WAR**

by James A. Wilson

In October 1984 the World Court handed down its decision regarding the Canadian/U.S. maritime boundary in the Gulf of Maine and Georges Bank. The boundary decision was a direct result of a failure of the two parties to negotiate and approve a treaty governing their conflicting claims and interests in the Northwest Atlantic. Settlement of the boundary, however, resolves only a small part of the outstanding differences between the parties. There still remains to be settled a variety of very difficult issues with regard to the management of transboundary fisheries resources and with regard to trade in fisheries products.

The trade problem is an especially burning issue at the moment. Atlantic Canada sells about 80 percent of its fisheries products in the United States and depends heavily upon the fisheries as a source of jobs and future development. Because of the social importance of the fishery, the Governments of Canada (both Federal and Provincial) have expended large amounts of funds on the development of new processing and harvesting facilities. The New England industry, which has not been the recipient of similar government largess, has cried foul; in August of 1985 it filed a petition for competitive relief from subsidized Canadian product. This petition asks that the U.S. government place a countervailing duty (tariff) on Canadian product just equal to the value of the Canadian Government subsidies. The petitioning action has not warmed the hearts of the Canadian Government or industry.

In what may appear to be a strange and almost contradictory move the Maine Fishermen’s Cooperative Association (MFCA) has initiated a proposal for free trade discussions with Canada. The seemingly contradictory nature of the proposal is attributable more to our preconceptions of what is meant by free trade than it is to inconsistencies within the New England industry. It is usually assumed that free trade means simply an absence of tariffs or other barriers to trade. This is, indeed, the long run goal of the MFCA proposal, but it is the way of getting from here to there that sets the MFCA proposal in a unique light.

In economic theory and in the practical laws and policies that we apply to international trade, there is an assumption that adequate markets will develop in the absence of tariffs or other barriers to trade. It is through exchange in these markets that the gains to trade are realized. The obvious corollary of this proposition is not often considered: with inadequate markets it is not likely that either party to the trade relationship will achieve the benefits that are usually assumed to occur. In New England and Atlantic Canada the market structure that governs the sale and distribution of fresh fish is particularly inadequate. The uniqueness of the MFCA proposal lies in the fact that the crucial part of the proposal suggests the proper approach to an eventual free trade situation is through the conscious creation of better market structures. It proposes that this be accomplished through joint Canadian/U.S. action.

The market problem the proposal seeks to address has to do with the cross-border and internal flow of product in both industries. Atlantic Canada and New England supply almost identical markets with an almost identical (species) range of fish. The daily supplies of fish at any individual harbor are usually highly variable depending on the movement of fish, weather, mechanical problems aboard boats and a variety of other factors. The final market for fish, on the other hand, demands a steady and predictable flow of product on a daily basis. This temporal and spatial mismatch of supplied and demanded product, means that fish has to be moved continually from harbors.
in which it might be temporarily abundant to harbors where processors are short of fish. This movement has to take place internally in each country and also both ways across the border. Given the large geographical range of the fishery, the highly variable nature of supply and the large number of species harvested (nearly 30), the problem of coordinating the movement of product, what economists call clearing the market, is immense.

In its current configuration, the fresh fish market in New England and the Atlantic Provinces does not coordinate the movement of product in an efficient manner. The problem can be looked at as an information problem. Some buyers are often caught short of product when at the same time some sellers are having a difficult time finding buyers. More often buyers obtain product they need and sellers manage to sell but only after considerable searching and time. The coordination process consumes two, three or more days – very valuable time when the product itself might have a shelf life of two weeks or less. In addition, one of the primary problems that makes trading in the market so difficult is the problem of quality. A buyer of fish can never be quite sure about the quality of fish offered for sale unless he is able to inspect them. This so complicates the trading process that the industry almost completely avoids the additional burden of pricing according to product quality. At the first sale of fish, all fish of the same species or market category get the same price regardless of quality. The result is a lack of financial incentives for the production of high quality product and, as one might expect, a tendency for very little effort to be expended in the production of a quality product. Overall, this very inefficient state of affairs arises because the information traders require for efficient exchange and for the enforcement of quality incentives is only available in the current market at very high cost.

Information about who is buying and selling, the nature or quality of their product, their ability to pay or deliver and a variety of other factors is crucial to the making of any transaction. Although most people don’t think of it in these terms, the low cost provision of this kind of information is really what markets are all about. To the extent that markets generate appropriate information inexpensively, they reduce the costs of buying and selling and, more importantly, make possible many transactions that otherwise might not be made. Put differently, it is this flow of market information – generated by the institutions of the market itself – that results in traders’ self-interested buying and selling getting the right fish to the right person at the right time; this is what is meant by efficient coordination through the market.

The specific approach suggested by the MFCA is very similar to the approach to the market/development problem taken within Maine itself. The new auction facility in Portland is designed to respond to the same kinds of market problems that are endemic throughout New England and Atlantic Canada. The Portland auction facility is unique in North America. Normally the first sale of fish takes place when the fish are still aboard the catching boat. The fish cannot be inspected for differences in quality and cannot be priced according to quality. Fish are also sold at a large number of private wharfs; with few exceptions there is no market where a fisherman can obtain bids from many buyers or where buyers can buy fish from many fishermen. The Portland auction changes this procedure by consolidating the supplies of many boats in one location, by putting those fish on display before they are sold and by making the results of each sale public.

Among other things, the MFCA proposal suggests that Canadian fish exported to the U.S. be sold in the Portland auction (via truck delivery), that similar facilities be put in place in Canada and that consideration be given to tying electronically those individual auctions. Coupled with changes in licensing and other procedures designed to create fair and equal access to each others’ markets, the MFCA proposal points to a basic restructuring of the Northwest Atlantic fisheries market.

What is unique about the MFCA proposal is that it recognizes the need to establish efficient market structures as a prerequisite to free trade. The proposal is, of course, simply a recognition of self-interest. But it does put the fisheries trade problem in a light that is very different from other industries with stiff foreign competition. Rather than demands for tariffs and protection, the MFCA proposal has the potential for converting a possibly degenerative situation (a mini trade war) into one that may truly achieve mutual benefits for both trading partners. In the short run the proposal is not inconsistent with the idea of the need for a countervailing duty to equalize the competitive advantage between the Canadian and U.S. industries. However, if the approach is successful over the long run, it should eliminate the need for Canadian government assistance to the Canadian industry (more efficient markets can be expected to contribute much more to a resolution of the employment and income problem in Atlantic Canada than might government assistance) and, consequently, the need for protective tariffs in the U.S. In short, the MFCA proposal represents a creative approach to the trade problem and one which, if successful, might serve as a model for much of our trade with Canada.

1The entire MFCA proposal is published in the October 1985 edition of Commercial Fisheries News, Stonington, Maine.
BALANCE

Once upon a time a man
Killed a blade of grass and ran.
How could he foresee
The crumbling song of Eternity?

Baffled dolphin and begging whale
Died with lobster, fish and snail.
Sea and man became hard salt,
As the world came ponderously to a halt.

— a bombard

INNER SPACE

THE GULF OF MAINE:
its history and future for research

by Robert S. Steneck

The Gulf of Maine is an oceanographically discrete body of water bounded by land from Cape Cod to Nova Scotia and to the seaward by Georges and Browns Banks. In the recent geologic past the gulf was scoured by glaciers which left the rocky shoreline, basins and banks that define this miniature sea within the North Atlantic.

The gulf is famous for its rich fishing grounds. It supported the first permanent fishing industry in North America, and records dating back to the early seventeenth century report an abundance of groundfishes such as cod and hake. For nearly 400 years this area has remained productive in groundfishes, shellfish and lobsters. Today, catches in the Gulf of Maine (and Georges Bank) comprise more than 80 percent of the total landings (in value) for the New England states, and of that more than 60 percent are fishes and invertebrates associated with the sea floor. Despite the history of commercially important bottom dwelling organisms in the Gulf of Maine, limited data exist on their distribution and abundance or how they interact, behave and feed on the sea floor. In fact, our knowledge of the sea floor sediments themselves is poor despite their importance to these communities as a source of food, habitat, and for nutrient regeneration. Perhaps of more significance is how little we know about the productivity of these stocks, since it is productivity that ultimately determines fishery yield.

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The question of benthic productivity is complex because it involves aspects of biological, geological, chemical and physical oceanography. Sampling techniques for bottom dwelling animals and sediments usually involve trawls, drags and grabs which are time-consuming and often give limited or dubious results. Furthermore, the complex bottom and rocky outcrops make such sampling techniques ineffective or impossible in more than half the gulf. It is also conceivable that the irregular bottom provides a refuge from fishing operations and consequently prevents some commercially important fishes and invertebrate species from becoming overexploited. This could partially explain why there have been 400 years of successful fishing in this area. Refining models beyond such speculation awaits scientific evidence regarding sea floor configuration and the distribution of sedimentary facies and associated organisms which, until now has been limited by available technology.

Manned undersea technology presents a unique opportunity to bring scientists physically to the benthos to study processes related to productivity in the gulf. Data collection on the distribution and abundance of commercially important organisms, together with their ecology, is now possible. To understand the ecology of any species it is necessary to study its diet, habitat, behavior and the associated flora and fauna. Such studies must be site-specific and nondestructive and should include in situ manipulative experiments. Without submersibles such studies would be impossible. Much of the published data lack the resolution available using this undersea technology and are consequently unable to answer the questions we are posing. The diets of commercially important species are known generally, for example, but lacking are site-specific data in the Gulf of Maine. In many cases considerably more data exist from outside the gulf where sandy and often polluted waters prevail. These data are of dubious utility to the unique Gulf of Maine system.

In the past, several University of Maine participants have independently examined the ways in which primary productivity is linked to the secondary productivity of commercially important invertebrates in intertidal and shallow subtidal habitats. Future collaborative studies will examine more explicitly the links between habitats, sediments, rock type or water mass in an attempt to develop a holistic model for the Gulf of Maine ecosystem.

A COMPLEX PUZZLE AND MISSING PIECES

The Gulf of Maine is an assemblage of ecosystems that are oceanographically linked and partially interdependent. Each ecosystem has its own trophic structure, biotic diversity and mineral cycles, but simultaneously it is interconnected to other ecosystems through physical and biological oceanographic processes (e.g., currents and biological migrations) occurring within the gulf. Arguably, a severe perturbation of any major ecosystem within the gulf will affect some or all of the others. For this reason, the Gulf of Maine should be regarded as a superecosystem, composed of parts that are most easily differentiated by habitat and geography.

Describing the superecosystem of the Gulf of Maine is difficult due to its diversity of habitats and environments. Studies into the myriad processes (e.g., productivity, recruitment, competition and predation) contributing to observed patterns in the distribution and abundance of organisms are difficult because they require separate studies of each ecosystem. Fortunately the ecosystems in the Gulf of Maine are somewhat simpler than most found elsewhere because glacially-induced extinctions have left any given habitat within the gulf relatively species-poor. This simplifies the determination of many ecosystem-level characteristics such as dominant organisms, interactions, energy and nutrient fluxes. The overall diversity of species in the gulf reflects its diversity of habitats. The University of Maine's coordinated study of the superecosystem requires that it be dissected into workable habitat regions and ecosystems.

The predominant habitat regions within the gulf:
- coastal regions comprising the turbid nearshore water;
- the central gulf, including the smaller banks and ledges;
- slope water complex which contains basins and the Northeast Channel;
- seaward border, which includes the larger banks (Georges and Browns);
- the water column that overlies the entire region and connects it to the western North Atlantic Ocean.

ZONATION IN COAST REGION

The coastal region consists primarily of rocky headlands, complex coves, bays, estuaries, mud flats and relatively few sand beaches. It is quite distinct from the sandy shores of Cape Cod to the south. Rocky headlands are separated by either expansive mud flats that exist in regions of reduced wave action or sand beaches where wave action is consistently heavy. Submerged sediment and rock distributions are the partial result of glacial action and marine processes of the past 10,000 years which have been strongly influenced by changing sea levels. Rocky intertidal and subtidal habitats contain many of the classical zones of organisms (i.e., barnacles, mussels, fucoid
algae, kelp and encrusting corallines) that are found worldwide. This two-dimensional habitat makes the study of structuring parameters such as growth, recruitment, and species interactions relatively straightforward, and thus much more is known about the ecology of rocky shores than any other habitat within the gulf. Rock habitats also have the highest per area rate of primary production. Although relatively simple and predictable, algal-benthic interactions are evident and well-studied in these habitats. However, little is known about the eventual fate of the enormous quantity of organic matter produced by macroalgae and exported from the rocky shores. In sharp contrast to the intertidal zone, the central gulf's banks, ledges and rocky outcrops are virtually unstudied, and preliminary observations indicate that their ecology is significantly different from the near shore regions.

Most of the benthos is composed of soft sediment on and in which an array of organisms dwell. Complex patterns in the distribution and abundance of organisms exist which are dependent on the in situ or imported organic productivity, sediment characteristics, geographic isolation, thermal stratification or the suite of other organisms such as predators or competitors living there. Deposit-feeding invertebrates dominate most sedimentary habitats, although a higher abundance of suspension feeding bivalves exists in nearshore regions. Offshore, both abundance and species diversity decrease markedly. These patterns are probably the result of reduced food availability as a function of distance from sources of primary production. Trophic linkages in benthic-pelagic coupling, nearshore-offshore rates on fluxes, and the relative contribution of water column versus benthic macroalgal productivity have not been well studied.

A unique aspect of the central Gulf of Maine is the deep water and basin community. The relatively warm bottom water in the gulf and the obvious connection to the deep sea via the northeast channel account for the affinity of the deep water community to that of the continental slope at depths of 1500 meters. Certain benthic invertebrates, however, have curious biogeographic affinities. For example, more than 50 percent of the amphipod species living at depths greater than 50 meters also occur on the other side of the Atlantic Ocean. Are these cosmopolitan organisms or relic populations of an ancient and much smaller Atlantic Ocean? Other new findings involve X-ray studies of sediments that reveal impressive evidence of benthic invertebrates living at great depths in the sediment (more than 50 centimeters) and indicate that sedimentation may not render organic matter unavailable since some organisms construct deep burrows exploring for food.

Regardless of the benthic community, the overlying biological communities in the water column are complex in both space and time. Regions of consistently high primary productivity are attributable to tidal mixing causing both upwelling and downwelling situations nearshore. Oceanic currents create upwelling over offshore banks. Spring phytoplankton blooms occur as the water stratifies and light penetration increases to regions of high nutrients. The enhanced production in the water column triggers herbivore and predator population pulses that deplete phytoplankton in the stratified offshore waters.

Chlorophyll patterns, indicative of the varying levels of primary productivity, are easily seen in satellite images, but absolute rates of production are unknown. Microbial loops include microheterotrophic bacteria that subsist on dissolved organic matter (DOM) and may consume 10 to 80 percent of the organic carbon. These microheterotrophs are fed on by larger protists such as flagellates in the 3 to 10 micrometer range, which in turn are fed on by copepods or ciliates in the 100 - 5000 micrometer range. Organic matter, mucus and feces from these organisms aggregate into marine snow which facilitates sinking, thereby connecting it to the benthos.

The abundance of particulate matter in the water column contributes to its turbidity: nepheloid layers. Nepheloid layers can be of pelagic or benthic origin depending on physically or biologically induced resuspension of sediments. Nepheloid layers render the benthic-pelagic boundary somewhat indistinct, and it is becoming widely recognized that a loosely packed fluff layer exists throughout much of the Gulf of Maine. The role of this fluff layer to benthic productivity is unknown.

Numerous organisms including benthic invertebrates such as sea pens, cerianthid anemones, scallops and the abundant demersal plankters living at the sediment - water interface may utilize the rich organic in the nepheloid layer. Euphausiids and mysids are among these demersal planktonic organisms, and their productivity, diets, and impact on the benthos from feces and bioturbation will require more study.

The study of vertical energy fluxes in benthic-pelagic coupling and horizontal energy fluxes in nearshore-offshore processes raises interesting questions concerning the carrying capacity of the Gulf of Maine. Such studies must be conducted to understand and ultimately predict the sustained yields our different fisheries can expect. Given increasing fishing effort and the gradual decline in the gulf's pristine habitat, which is the inevitable result of the encroachment of civilization, studies such as these are essential and timely. Only by studying and understanding the complex interactions in this superecosystem will it be possible to retard the negative impact of human activity and protect and enhance the positive aspects of human interaction and enjoyment of our ocean resources. See photos page 18.
Predatory snails feeding on barnacles.

A rock crab on an edible blue mussel.

A grazing periwinkle on rockweed.

A Maine lobster near its lair next to a boulder covered with crustose coralline algae.
shape n. that quality of a thing which depends on the relative position of all points composing its outline or external surface; physical or spacial form

—Webster's New World Dictionary
second college edition

THE SHAPE OF MUD AND ITS IMPORTANCE TO MARINE ANIMALS

by Les Watling

When most of us think about shape, the words round, square, triangular, come quickly to mind. If we think about it a little more we might come up with rough, smooth, or angular to describe the outline of an object. But how about a description such as $1 + 0.1692 \cos(2\theta - 121) + 0.1021 \cos(3\theta - 39) + 0.0932 \cos(4\theta - 24) + 0.0354 \cos(5\theta - 187)$? While this may seem unlikely, it is actually the result of a method known as Fourier Analysis which can be used to describe mathematically the outline of an object. This description is the result of a complex process involving computers, television systems and small particles.

To describe quantitatively the shape of an object, one must first obtain an accurate representation of its outline. For the present time we will concern ourselves with two-dimensional outlines. There are several methods by which this can be done. The simplest is to trace the object on a grid system and then record from the grid a large number of coordinates that describe all features of the outline. This is obviously a very time-consuming method, and few objects can be analysed. Another method is to trace the object on a digitizing tablet which is connected to a computer. This allows the coordinates describing the object’s outline to be recorded automatically in the computer’s memory. While this method is faster than the first, it is subject to certain unique types of errors. One of these is a direct result of the varying tracing abilities of different people.

The best method, and the one that is currently being developed in our laboratory, is to use a television camera to obtain an image of the object. This image is then processed in such a way that the outline of the object is determined. Each pixel (picture element) in the television image that the outline traverses is then recorded in the

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computer's memory. Since all pixels are the same size, the outline of the object can be completely described as a series of directions through which the outline moves. For example, there are only eight possible directions in which the outline can move, and these can arbitrarily be assigned the values 1 to 8. If '1' is straight up and '3' is to the right, then '5' is down and '7' is to the left, with the other values being the diagonals. The number '113335777' would describe a rectangle 2 pixels high and 3 pixels wide. Clearly the outline of this rectangle could be obtained and accurately described in a repeatable manner.

Once an outline has been obtained, the computer is employed to perform the Fourier Analysis. This is essentially a technique that searches for repeatable signals (harmonics in the waveforms) in the numbers describing the outline. The output of this analysis is a series of amplitude values for each harmonic analysed. These amplitudes are the heights of the waveforms associated with each harmonic. If an object is very triangular or very rectangular, it will have high amplitude values associated with the third and fourth harmonics, respectively. As we analyse for the higher-numbered harmonics, we are able to examine features in the outline that are very small. If an object has high amplitude values for the higher-numbered harmonics, it means the outline is rough. If these amplitude values are small, then the outline is smooth. So, now we have a method to describe quantitatively very small features, many of which may not be discernible by our eyes.

Of what importance might the shape of an object be to marine animals? In brief, we can say that the amount of food obtained by several of the organisms consumed by the Gulf of Maine's groundfish may be determined by the shape of the sediment grains they put in their mouths. To explain all this, let's back up a little. Several of the groundfish species in the Gulf of Maine, (for example, haddock, flounders, and young cod and hake) eat small worms and crustaceans, and some brittle stars. Most of these animals are known as deposit-feeders, that is, they eat mud with the intention of digesting out of that mud as much organic matter as they can. While we commonly think of mud as dirt that is wet, on the sea bottom it actually consists of a large number of dirt particles (sediment grains) that are coated with small amounts of organic matter and a small number of plant and animal pieces, with a few very tiny animals mixed in. By eating this mud an animal can obtain most of the nutrition it needs.

It has been known for a long time that many of these mud-eaters took into their mouths only those sediment grains that were of a certain size. Obviously, certain particles would just be too big to fit into their mouths. But what could be the reason for eating only large numbers of small particles? It has been suggested that there is more organic matter associated with tiny particles than with large ones. Also, large pieces of organic matter in the mud tend to have large numbers of tiny grains in them. However, there has also been some circumstantial evidence that sediment grains that were angular tended to have stronger coats of organic matter than did smooth grains. But since the shape of a grain could not be quantified this observation could not be tested.

With the development of the Fourier Analysis technique, it is now possible to determine whether a deposit-feeding animal might select a grain on the basis of its shape. In order to test this idea we used a worm which lives in the mud flat adjacent to the Darling Center. This worm uses tentacles that may be as long as half a meter to remove sediment grains from the surface of the mud flat and transport them to its mouth. We examined the sediment grains in the guts of several animals and compared their harmonic amplitude values with those from the mud flat surface where the animals were feeding. There were no differences in the values for the lower numbered harmonics, but as the harmonic number increased beyond 8 the differences became stronger. This told us that there was no determinable difference between the gross shape of the grains eaten versus those available in the mud, but that the worms were somehow obtaining from all the available grains in the mud flat those that had slightly rougher surfaces.

The question: Are the worms actively selecting grains with these features or is there some mechanistic explanation for what we observed? Our current hypothesis is that the grains with a rougher surface texture tend to have the higher amounts of attached organic matter. A worm with a long feeding tentacle is dependent on the selected grain staying attached to the tentacle while it is being transported to the mouth, so it uses mucus as a glue. We think that the adhesive forces between the mucus on the tentacle and the organic matter on the particle are what keep the grain on the tentacle. Thus, a grain with a greater amount of organic matter bound to it is more likely to make it to the animal’s mouth. The surface roughness of the grain as measured by Fourier Analysis may be an indicator of this relationship.

Is it likely that areas of the sea bottom that are characterized by sediment grains that are more angular, or rough, might support more bottom feeding animals, or at least, different kinds of animals? All of this remains to be investigated, but we are at least now coming to realize that the shape of a sediment grain may be as important, or perhaps more so, than size. Since many of the sediment grains on the bottom of the Gulf of Maine were deposited by glacial activity they may have rougher surface features than those brought long distances by rivers. No one has yet considered the implications of this aspect of the geological history of the Gulf of Maine on the richness of its fauna.
The eastern Maine coast is rugged and unspoiled. High, rocky cliffs and headlands support thick, low stands of pine and spruce. There is very little evidence of human habitation. Below the cliffs, the water is clear and cold and dotted with lobster pot buoys, a sure sign that the people who do live here make their living from the sea.

Two things that the fishermen in eastern Maine have to contend with are fog and strong currents. Tides in eastern Maine rise and fall as much as 20 feet. The tidal currents rush in and out of the Bay of Fundy through the Grand Manan Channel, a narrow expanse of water that separates the mainland from Grand Manan Island, a large Canadian island located only 5 to 10 miles offshore. The current is so strong that it thoroughly mixes the water from top to bottom, thus accounting for the low surface water temperatures and, as warm, moist air comes in contact with the sea surface, for the fog.

From a small boat, the most remarkable feature along this coastline is the sudden boiling of the sea surface as moving masses of water at the bottom encounter submerged rock ledges. This stretch of ocean has attracted...
schools of herring which have come here to spawn every fall for as long as anyone can remember. The spawning population of herring has been the subject of a three-year study funded by the University of Maine Sea Grant Program which is being conducted by researchers from the University of Maine, the Maine Department of Marine Resources, and the Bigelow Laboratory for Ocean Sciences.

The Atlantic herring Clupea harengus is a valuable fishery resource for the State of Maine. More than $60 million were generated in 1980 by the harvesting and processing sectors of the industry. Landings of 47 million pounds (21,250 metric tons) accounted for 25 percent of all the marine fish and shellfish landed in Maine in 1984. Although herring live to age 10 or older, most of those harvested by Maine fishermen are two and three years old. These juveniles (sardines) are caught primarily in the many embayments along the Maine coast and canned for human consumption. Although not as important as they were in the 1940s and 1950s, these canneries still provide seasonal employment in many coastal communities. Adult herring are harvested in smaller quantities, primarily because of low market demand.

The Maine herring industry has always been plagued with extremely variable catches. Poor catches during the past four years are currently a cause of concern in the industry, but a look at historical production figures (Figure 1) reveals that this has always been a boom and bust fishery. Catches have varied by as much as 180 percent from one year to the next. These fluctuations are difficult to predict and are believed to result from changes in the number of herring in the population and the effects of poorly understood environmental and biological factors such as water temperature and the abundance of predators such as bluefish and whales which can actually herd schools of sardines into inshore bays where they are more easily harvested.

Herring, like some other species of marine fish, produce many eggs (a 12 inch female produces about 100,000 eggs), but the percentage of offspring that eventually survive to reach a harvestable size is extremely low. Therefore, very small changes in the mortality rate of eggs and larvae can have a very large effect on the size of the juvenile population. The process by which young fish survive to reach a harvestable size is termed recruitment and is a combination of the number of adults which spawn and the survival rates of eggs, larvae, and juvenile fish up to age two. All the fish which are born in the same year constitute a year class. Variations in recruitment therefore produce year classes of different sizes. Infrequent large year classes, such as the 1970 year class, can sustain high catches for several years (Figure 2). Understanding the sources of recruitment variability is therefore an important step in the prediction of year class size in this highly variable and important fishery. This understanding comes from studies of herring reproduction and recruitment processes.

Figure 2. Catch of 1970-1973 herring year-classes from Jeffrey’s Ledge from 1972-1976 showing persistent strength of 1970 year-class.

Atlantic herring spawn in several locations in the Gulf of Maine. These include Jeffrey’s Ledge (in the southwestern Gulf of Maine), the southwestern tip of Nova Scotia, and various locations along the Maine and Massachusetts coast. Herring spawn in the Gulf of Maine during the fall (August to November, depending on location). Unlike most other species of marine fish, herring deposit eggs in cohesive mats on the bottom, generally in depths of 25 to 50 meters (75-150 feet). These egg beds vary in size but

Figure 1.
are generally less than one square mile in area. The eggs incubate for a week to ten days until they hatch: herring larvae are about 6 mm (¼ inch) long at hatching and carry a yolk sac which supplies them with their own food supply (Figure 3) until the age of about one week when they begin feeding on microscopic planktonic animals.

Figure 3. Recently hatched herring larva with yolk-sac. Actual size about ¼ inch.

Schools of mature herring begin congregating along the eastern Maine coast in July and spawn in August and September. In 1983, 1984, and 1985, with the help of lobster fishermen from Cutler and Bucks Harbor who have reported herring eggs on their lobster pots, thirteen spawning sites were located along the 30 miles of coast from West Quoddy Head to the Libby Islands (Figure 4). Herring spawned at two of these sites (C and E) in all three years. Eggs were observed with a video camera mounted in an unmanned remotely-operated underwater vehicle in September 1985 in two locations.* On the bigger of these two egg beds (site L), eggs completely covered the bottom in a carpet less than one inch thick in 35 meters (100 feet) of water over a distance of 250 meters (800 feet). Analysis of videotapes which were recorded

Figure 4 (two maps). Egg bed locations in eastern Maine, 1983-1985.
inside and outside the egg bed and of bottom sediment samples will enable researchers to characterize the egg bed habitat and perhaps to determine why herring select specific locations to deposit their eggs. Future underwater egg bed work in eastern Maine will be directed toward further characterizing egg bed habitats, estimating the size of individual egg beds, and determining the extent and causes of egg and early larval mortality.

In addition to locating and surveying egg beds there are three other objectives of the Sea Grant herring project. They are to determine

- the distribution, abundance, and dispersal of larvae which hatch on this spawning ground;
- the distribution and abundance of planktonic organisms which serve as food for the larvae;
- the physical and biological characteristics of the coastal waters which affect larval dispersal, larval food production, and larval survival.

Preliminary results are based on the analysis of samples of larvae and zooplankton (free-floating microscopic animals) collected in fine-meshed nets deployed from the University of Maine’s research vessel R/V Lee and from measurements of temperature, salinity, nutrients required for the growth of phytoplankton populations which support the entire openwater food chain, and chlorophyll, the photosynthetic pigment in plant cells which converts sunlight into plant tissue. Preliminary results have produced the following picture of larval herring production, dispersal, and survival in eastern Maine coastal waters.

Within several weeks after the eggs begin hatching, larvae have already been transported downstream from the spawning ground almost as far as Mt. Desert Island (Figure 5) by the currents which flow from east to west along the coast. Net westward displacements of 8 and 14 km/day (5-9 miles/day) were indicated by surface current measurements at two locations in the eastern coastal Gulf of Maine in September 1985. Currents of this magnitude are capable of transporting herring larvae along the entire length of the Maine coast within several weeks after hatching. In fact, larvae from eastern Maine are known to reach at least as far west as the Sheepscot River in midcoastal Maine by early October.

As these larvae drift westward and absorb their yolk sacs, they begin feeding on the small, developmental stages (nauplii) of tiny crustaceans called copepods. Densities of copepod nauplii were extremely low in the vicinity of the egg beds in September 1983 and higher in inshore waters near Mt. Desert Island (Figure 6). Thus, larvae which survive the transit from the spawning ground to this downstream location have enough to eat, but many larvae are presumed to die in transit because their food supply is so low. The importance of predation by organisms which feed on recently hatched herring larvae is not yet understood.

Measurements of inorganic nutrients made in eastern Maine coastal waters in September 1984 indicate that there was plenty of nitrogen available on the spawning

![Figure 5. Abundance of herring larvae per hundred square meters in vicinity of egg beds in eastern Maine, September 13–15, 1983.](image)
ground to support plant growth, but chlorophyll concentrations were extremely low, suggesting either that no photosynthesis was taking place or that the plant life was being consumed by herbivores such as copepods as fast as it was being produced. Since adult copepod densities over the egg beds are low, the more likely explanation is that the extreme vertical mixing of the water column on the spawning grounds prevents the phytoplankton cells from spending enough time in the sunlit surface waters to photosynthesize. Plant cells which cannot produce their own food supply perish. As the water mass moves westward, downstream from the spawning ground, the degree of vertical mixing diminishes and the phytoplankton begin photosynthesizing because they spend more time in the near-surface sunlit waters. At the same time, the copepod populations begin to thrive and reproduce, but in so doing, they consume sufficient quantities of phytoplankton to keep chlorophyll concentrations low. Further downstream in the vicinity of Mt. Desert Island, copepod eggs have hatched and the density of copepod nauplii increases to a level that helps larval survival and growth. The optimum reproductive strategy for herring which spawn in coastal waters with a net unidirectional flow may be to deposit eggs in a tidally-energetic environment upstream from an area where food densities increase as larvae begin to feed. If so, the location of the egg beds would be crucial.

So far these are only hypotheses, but they provide a conceptual framework for considering how variations in such factors as current speed, nutrient concentrations, sunlight, and the location of the egg beds could affect larval herring transport and survival and, a year and a half later, the number of juvenile herring which support the Maine sardine fishery.

Although the eastern Maine spawning ground is not the only source of larvae for the coastal Gulf of Maine sardine population, the downstream transport of larvae distinguishes eastern Maine as probably the most important spawning ground along the coast. Further analysis and interpretation of the data which have already been collected during the course of this study plus the additional results of future work should provide tests of these hypotheses and lead to more complete understanding of the recruitment variability of this important Gulf of Maine resource. This project illustrates the importance of multidisciplinary studies which incorporate elements of fish population dynamics, larval fish ecology, and physical and biological oceanography.

*Funds for the use of this vehicle were provided by a grant from the NOAA National Undersea Research Program at the University of Connecticut at Avery Point. The vehicle (MINI-ROVER) was owned and operated by Eastern Oceanics, Inc., of W. Redding, CT.*
SEISMIC PROFILING:
The Search for the Submerged Geological Record in the Gulf of Maine

by Daniel F. Belknap
and Joseph T. Kelley

Investigating the geological record of deposits on the land surface of Maine requires a variety of equipment, but much of the work can be accomplished very well by studying maps and air photos and even by digging with a shovel in gravel pits. Underwater, however, a remote sensing technique is required to reconstruct geological history. For the past three years we have been using high resolution seismic profiling, a sound wave system related to sonar, to obtain images of the nature and thickness of sediments under the sea floor.

The importance of this submerged record is becoming clearer, since we now know that sea level fluctuations have played a large part in the geological evolution of Maine during the Quaternary Period: the time from the last Ice Age to present. These sea level fluctuations have alternately covered the coast of Maine up to Millinocket and Bingham (132 meters elevation) and subsequently fallen to 65 meters below present sea level, exposing several tens of kilometers of the inner Gulf of Maine.

The driving force behind these changes in sea level may be found with the changes in the earth’s climate and the resulting advances and retreats of the great Laurentide Ice Sheet. As the ice advanced over Maine, it eroded the preexisting sediments and scoured the bedrock. This great ice sheet extended to southern New England and Long Island, and across Georges Bank. The great weight of the ice caused the earth’s crust to subside by several hundred meters. Simultaneously, sea level had been lowered, because all the water that went to build the great ice sheets came from the ultimate source of the oceans.

Approximately 18,000 years ago the glaciers had passed their peak and begun their slow retreat northward. This retreat was accomplished by melting and by great streams of ice which broke up into icebergs which were carried to warmer seas. These mechanisms thinned the ice over Maine, allowing the crust to rebound upward as the weight was released, a phenomenon known as isostatic rebound. Again, however, the ice volume and sea level were linked; as ice melted, sea level rose.

Approximately 13,500 years before present, the front of the glacier had retreated to the present coast of Maine, and was in direct contact with the sea. For a time, the retreat of the ice was so rapid that the crust of the earth did not rebound fast enough to keep out the sea, and the coastal lowlands of Maine were inundated. Rebound slowly became dominant, and the sea retreated beyond the present coastline.

As the ice was melting and the coast was drowned, an abundant supply of mud and sand collected on the sea floor, forming the Presumpscot Formation, a blue-grey sticky sediment found in most of southern Maine today. In addition, at the highest level of the sea a series of sand and gravel deltas were built out into the sea, from the southern shore of Sebago Lake in southern Maine to Pineo Ridge in Washington County. These features have been studied in detail by Woody Thompson of the Maine Geological Survey and several UMO students including Kris Crossen, Carolyn LePage and Sarah Miller. Figure 1 shows the extent of the submergence and the area in which the Presumpscot Formation and the glaciomarine deltas are found.

As rebound continued, the sea withdrew to a level at least 65 meters below present sea level. We know this because the Presumpscot Formation and other sediments were exposed to the air and underwent a process of drying and hardening as soil formed. In addition, this surface was eroded by streams which cut deep gullies and river valleys. These features can now be seen in seismic profiles and penetrated by cores.
Figure 1 - Location map of Maine, showing distribution of the Presumpscot Formation and glaciomarine deltas.

The sediments produced by the glacier as it retreated also were eroded by large streams, such as the Kennebec River. The sand and gravel were brought down the river to the sea and formed a large delta.

Deltas are excellent indicators of the level of the sea, and the presence of the ancient Kennebec paleodelta 50 to 70 meters below present sea level is a distinctive marker for sea level lowering. Unfortunately, we don’t know the precise timing of this sea level lowstand, since we have no cores with datable material from those sites as yet. After the lowstand, sea level began to rise rapidly as global sea levels rose and local isostatic rebound slowed.

Finally, about 5000 years ago, sea level in Maine reached about 6 meters below its present level and has been rising at a decreasing rate up to the modern era. There are some indications that sea level has again been rising very rapidly in much of the United States, and at accelerated rates in some areas including Eastport, Maine. The reasons for this recent rapid rise are unclear; possibly they include earthquake activity and crustal warping. Active research has been continuing at UMO and the Maine Geological Survey over the past six years to try to identify the rates of change and possible causes.

Figure 2 is a summary of the sea level changes identified on the Maine coast, based on radiocarbon-dated marine shells, salt marsh peats, and indirect evidence from remote sensing by seismic profiling. The seismic profiling investigations which we have undertaken are concerned with identifying the sediments produced at the various stages of this sea level rise and fall. The study is particularly important as the Presumpscot Formation is studied for uses such as low-level nuclear waste storage, and because this unit which underlies much of coastal Maine has proved to be susceptible to landslides on steep slopes. In particular, however, our scientific interest arises from the response of coastal sedimentary environments and the Gulf of Maine to uniquely rapid and extreme sea level changes.

Figure 2 - Summary of local relative sea level change based on marine shells, peat and seismic profiling evidence.

IN THE FIELD

How do we collect seismic data? A typical cruise starts at dawn at the Ira C. Darling Center and finds us loading our electronic equipment onto the R/V Lee or R/V Miss Bess, two lobster boats owned by UMO and outfitted for research. Captain Mike Dunn starts the diesel engine and warms up the loran and radar navigation equipment as we store the last of our gear. Usually there is a crew of two or more graduate students, including Craig Shipp and Weiming Tu of the Oceanography Program and Brad
Hay of Geological Sciences, who are gathering data for their theses, in company with the principal investigators. After an hour or more of back-breaking but organized pack horse labor, the boat is ready to depart.

If the survey site is within 20 nautical miles of Walpole, we’ll use the Darling Center as our base; if not, we’ll drop into a convenient marina at night. Towed behind the RV/Lee is a catamaran, the active sound source for the ORE Geopulse, a high resolution, deep-penetration seismic device. Another device is the Raytheon RTT1000 for shallow water, fine detail work which was made available through National Science Foundation research grants.

At sea, the gear is towed by cables and attached to brackets. There are three main systems to set up: the sound source, the receiver-amplifier, and the recorder. The sound source is basically a large plate which is driven by an electromagnet to create a high-intensity pulse of low frequency sound. The electromagnet is driven by a capacitor bank which is triggered at a very precisely repetitive rate. This sound is sent out into the sea, and penetrates through the water and into the underlying sediments. Part of the sound wave reflects off the bottom, while part penetrates farther and reflects off underlying strata. The reflected sound returns to the ocean surface. Here the second part of the system comes into play: the receiver. The most important part of the receiver is the hydrophones, essentially a series of microphones in an oil-filled tube. The sound picked up by the hydrophones is amplified, filtered, and transmitted to the recorder, the third basic component. The recorder we use is an analog paper chart, but more sophisticated digital electronic devices can be used. A tape recorder is commonly used to replay the data at a later time.

Figure 3 is an example of the record from this chart recorder. The top of the chart is the water surface, while the next prominent line is the bottom of the sea. Below the bottom can be seen multiple reflections from sedimentary strata and the underlying bedrock. As this record is produced, we keep a careful log of navigation from the loran and radar, noting our position every five minutes, or more frequently if necessary. We try to interpret the features as they appear, so we may plan the remainder of the cruise, but major analysis has to wait our return to the laboratory.

The boat will cover approximately 50 nautical miles in a day’s effort, in a grid or zig-zag pattern over the fea-

Figure 3 - Example of the output of the ORE Geopulse system over the Kennebec paleodelta. The top of the record is the sea surface; the first strong return is the sea floor. Below the real record is a line drawing interpretation. (t = till, sd = stratified drift, gm = glacio-marine mud (Presumpscot Formation), m = Holocene mud, sq = Holocene sand and gravel, br = bedrock, and ng = natural gas bubbles within the Holocene sediment).
tures of interest. Due to the expense and physical effort involved, the cruises must be carefully planned in advance, but flexibility is left for the unexpected, serendipitous discovery. Flexibility is also required for common breakdowns, problems with the boat, or electronic snafus. Our captain’s genius at jury-rigging often helps, but sometimes we sweat over the electronics circuit diagrams and wield the solder gun.

At the end of the day, we cruise back into port, often after dark. Threading our way through the navigation buoys and past the mud flats we finally dock or drop anchor. Often the day ends in sleeping bags on the fantail, under the stars and among the mosquitoes. At the end of the cruise, it’s more lugging of gear, and a trip back to the lab to begin the long process of data analysis.

**BACK IN THE LAB**

The goal of all this data collection is to identify the types of sediments within the coastal zone, their sequence, thickness and degree of preservation, and finally to relate these patterns to their history. We have pieced together a general history of the coast, and specifics for several of Maine’s estuaries, but much remains to be done.

For most of the Maine coast, the record begins with the glacially sculpted bedrock, smooth and worn by the ice. On top of this rock lies till, a stony jumble of many sizes of sediment deposited directly from the ice. This till may be banked up into ridges known as moraines, where the ice hesitated for a season or longer. On top of the till is usually found the Presumpscot Formation, the sticky blue-grey glaciomarine mud produced in the deep, cold waters seaward of the ice. Finally, associated with till and glaciomarine mud is a better sorted sand and gravel, known as stratified drift. This is representative of outflows of meltwater at the glacier front.

On top of all these deposits, laid down approximately 13,500 to 11,000 years before present, is an erosional surface, known as an unconformity, representing the time of sea level lowering. This surface persists to 65 meters below present sea level. Finally, above this unconformity are found the sediments of the Holocene, or Recent, period comprising the last 10,000 years. These sediments include beach sands, estuarine muds, and salt marsh peats. We find that as sea level has risen, the coast has drowned and the sequences of environments have marched inland in pace with the rising sea. Reconstruction of this history allows us to predict that as sea level continues to rise, coastal erosion and drowning will continue, salt water environments will encroach on the upper parts of the estuaries, and this conveyor belt of sediments and sea level rise will continue its relentless march inland.

![Diagram](image.png)

**Figure 4** – Series of block diagrams demonstrating the evolution of the Kennebec paleodelta system during sea level changes during the past 13,000 years.
A specific example of the reconstruction of this history has been done on the Kennebec paleodelta, near Popham and Small Point. As mentioned above, this feature is useful for determining sea levels 9500 years ago, but it is also critical to understanding the coastal problems of Popham Beach and Reid State Park. Figure 4 shows a series of block diagrams demonstrating their evolution. About 13,000 years ago, ice was stranded near the present coast, and it produced till. As the ice retreated, the massive influx of mud produced a thick blanket of Presumpscot Formation which was draped over the entire submerged area. From this time to about 9500 years ago, sea level dropped very rapidly, producing gullies and channels.

Sediments were brought down the Kennebec River and began to build a delta at its mouth. As sea level rose once again, the delta continued to build until the flow down the Kennebec was reduced by climatic change. Finally, during at least the past 5,000 years, sea level has drowned the former delta, while coastal erosion has redistributed its sands into the modern beach systems. Thus, the clean white sands of Popham Beach and Reid State Park owe their presence to the last great ice sheet and the efforts of the Kennebec River before it was drowned to above Brunswick.

The information presented here has been the result of three years of effort supported by external grants and UMO funds. It also represents the combined efforts of the authors, their graduate students, and the previous work by several members of UMO’s oceanography, geology and Quaternary programs, including Hal Borns, Detmar Schnitker and Ken Fink. This work is continuing, in large part through the support of the Center for Marine Studies.

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**OUR COVER ARTIST: Michael Lewis**

A few years ago when I first encountered Michael Lewis’ paintings I was stunned by his unusual technique of working with the thinnest and most transparent glazes of luminous oil paint on a specially smooth paper surface. With quick and immediate touches, strokes, and wipings of color, he was capable of evoking the infinite depth of light-filled landscapes, of threatening and grandiose skys, or warmly illuminated interiors peopled with small but incisively characterized figures. They gave the specific religious mood to the pictures. It was then a new achievement for the artist, following long years of laboring with more traditional painterly techniques on canvas and more conventional and personal subject matter. It was clear, Michael Lewis had made a breakthrough not only for himself. His work revived for modern sensibility the mythological and religious depth of older landscapes like those of Turner and Claude Lorrain.  

**Dr. Konrad Oberhuber**, Curator of Drawings, Fogg Art Museum, Harvard University  
Rome, March 8, 1983

Landscape painting is a genre which, in our time, has been dominated by the influence of photography. Michael Lewis, however, expresses his feelings about landscape in turpentine-on-paper washes that link him with the great European landscapists of the past. His works... contain tiny figures, which on close inspection resolve themselves into Biblical groupings... and other themes recalling such masters as Claude and Rubens. The artist is a professor of art at the University of Maine and his work instills landscape with timeless themes.  

**Robert Taylor**, The Boston Globe

My efforts at being an outdoor painter have shown me clearly that I find the physical world somewhat lacking if I stop thinking that there is something going on beneath the appearances. The paintings are about manifest and hidden, light and shadow, good vs. evil, or belief/participation vs. despair. They are about faith and optimism and love... and especially the seeking of some still unfathomed significance that pervades the universe and ties us to it. It is the excitement and promise of this search that gives the energy to keep working.

**Michael H. Lewis**, Orono, Maine  
August 24, 1985— from a letter to Konrad Oberhuber

Michael H. Lewis is a Professor of Art at the University of Maine. He earned his B.S. degree in art education from SUNY, New Paltz, N.Y., in 1963; an M.A. degree in painting from Michigan State University in 1964; an M.F.A. in painting from SUNY, New Paltz, in 1975.

A few highlights of his professional career include shows at the Van Buren/Brazelon/Cutting Gallery, Cambridge, Mass; the Uptown Gallery, Madison Ave., New York City; Congress Square Gallery, Portland, Maine. Twelve of his works are in the Permanent Collection of the Fogg Art Museum, Harvard University, and he was commissioned by the Muskie Family to paint a portrait of Secretary of State Edmund S. Muskie in 1983.

Since 1966, he has been a member of the Art Department faculty at the University of Maine, where he is widely regarded with affection and respect.
IN THE CLASSROOM

by Michael Brody

The ocean, a familiar and essential part of Maine life, has molded the State's past and continues to shape her future. Because of its multiple influences on Maine's citizens, the sea provides living models in a wide range of subjects: ecology, economics, conservation, natural resource management, recreation, community development, international law, fisheries biology, etc.

Teachers may use the highly integrated relationships in the marine world, which are a familiar part of schoolchildren's heritage, to illustrate complex intellectual concepts. By so doing, teachers are able to bring science into a familiar context and enhance student understanding.

The College of Education has taken an active role in promoting marine studies in Maine's public schools; curriculum guides and teacher workshops have been developed to further awareness of marine studies in public schools, and the programs have worked to help bring schools into compliance with the Educational Reform Act of 1984 which requires that state-wide student achievement tests include science topics.

With about 10 years experience in marine education efforts in Maine to its credit, the Northeast Marine Education Program (NEMEP) has begun programmatic research to assess these efforts. The recent United States/Canada maritime boundary dispute, with its far reaching consequences into most areas of marine life, has provided the mechanism for one such study.

A research team of UMO education students has been working with public schools to determine what students do and don't understand about the Gulf of Maine. The NEMEP team interviewed 226 students equally divided among grades 4, 8, and 11 in 12 public schools. The interview format was determined by analyses of primary documents concerning the Gulf of Maine which were presented at the World Court in The Hague, Netherlands.

The half hour student interviews covered areas of marine geology, physical and chemical oceanography, use of the ocean's resources, marine ecology, and natural resource decision-making. (The research does not represent survey techniques of an entire population; however, the qualitative results describe what we believe to be essential information for the effective design of future marine education programs.) After each student interview was audiotaped and analyzed, student responses showed that mean interview scores for each marine concept at each grade level were low and reflected only a partial understanding of the topics. Overall totals indicated that students understood only a few marine science and natural resource concepts, with only minor improvement through the grades. Finally, the researchers constructed generalized student statements of correct understanding for each marine concept; these partially correct statements indicate important ideas missing from the students' intellectual grasps.

Students' misconceptions were also identified: erroneous ideas which can significantly impede future learning. Misconceptions and partial understanding form the major target for future programs. From the data, it is clear that students learn a few basic marine concepts in elementary grades which they can then apply to issues concerning natural resources. Students do not, however, seem to acquire new concepts or learn to differentiate among discrete concepts.

The results of the study can be used by educators to introduce more effectively new ideas to students based on existing knowledge of the subject. The results facilitate more effective marine education activities.

A detailed report, including tables of essential content, existing student knowledge, missing concepts and misconceptions, is available from NEMEP, 206 Shibles Hall, UMO, Orono, Maine 04469.

Acknowledgments

NEMEP research is supported, in part, by funds from the UMO Faculty Research Funds. Collaborative researchers include Andrea Abbott, Roger Brainerd, Robert Constable, Cindy Dunham, Sandy Greenwood, Jerry Hagen, Tanis Jason, Helmut Koch, Andrea Lord, Judy Markowsky, Diane Pelletier and Michael Shirley.
NOBODY TOLD THE BUMBLEBEE HE Couldn’T FLY

Aerodynamically, the bumblebee cannot fly. And, according to Herb Hidu, it’s a good thing the bumblebee never realized he consistently does the impossible. The impossible and the unexpected are what research is all about, he says. Join us as we explore the accidental magic of science with Herb Hidu, Maine’s internationally renown pioneer and expert in shellfish.

science and serendipity

by Herbert Hidu

It’s my observation that many innovative and important scientific advances come as chance, or fortuitous, byproducts of other scientific projects. The structure of science in the United States makes this so. We write proposals for funding, which give us the framework or working environment within which the serendipitous advances come about if only we have an open eye to see them as they happen.

A good example: our Sea Grant funded projects in aquaculture throughout the 1970s. The University at that time embarked on a rather unusual approach. A flowing seawater hatchery facility was constructed on the coast, and faculty, graduate students and extension people were asked to do what they could to help create a new coastal industry for the state. Early, we did what seemed logical, but the path became tortuous and circuitous. First we evaluated the potential of Maine environments to grow oysters and mussels in an economically efficient manner. With success, we encouraged private citizens to experiment with European oyster culture by purchasing seed which was available only from west coast commercial hatcheries.

True to Murphy’s Law, in the mid-1970s the California shellfish hatcheries dropped out due to biological problems. With the vast scientific expertise and facility at hand at UMO, the obvious thing to do was for the University to supply shellfish seed on an interim basis until either the remote sources could be shored up or local commercial sources developed. Embarrassingly, it took us three years from when the decision was made until significant numbers of seed oysters were available for sale. Simply, what had worked for us on a bucket scale was inadequate at the production scale. Much useful research, particularly by graduate students, aided in the scale-up process. For example, we learned of the feeding role of a particularly troublesome protozoan, Urometa marina; we learned of physiological compensation mechanisms in bivalve shellfish by investigating the Maine intertidal zone as a hatchery nursery culture area; we learned of setting responses in oyster larvae in our attempts to develop our own cultchless setting procedure.

But most importantly, by indulging in the seed production exercise, we had created the physical and psychological environment for fortuitous advances to happen. Typical of these advances are

- production of the world’s first triploid shellfish, now of four species;
- development of biological fouling control in aquaculture;
- development of hatchery techniques for Maine’s soft-shelled clams.

At the time, these were just interesting research diversions, but now are among our most important scientific contributions and form the basis for much of our ongoing research.

Herbert Hidu is Professor of Animal and Veterinary Sciences at UMO. He earned his Ph.D. at Rutgers University, and his research interests focus on shellfisheries biology.
Our production and evaluation of triploid shellfish was the result entirely of fortuitous circumstance and was made possible by the presence of our production hatchery. *Triploidy* is the condition of having one extra set of chromosomes in each cell of animals and plants which generally adds vigor by one mechanism or another. Development of polyploid (any multiple sets of chromosomes above the normal two sets per cell) plant varieties has long been the mainstay of land agriculture; however, production of polyploid agricultural land animals has not been feasible because of their reproductive sterility. More recently the salmonid fishes have been the subject of much attention, including the recent work of Dr. Jon Stanley of the Maine Cooperative Fishery Unit at UM Orono. At a Sea Grant site visit to consider continuation of Jon’s fish work, a panel member, Bill Shaw, asked Stanley whether we had ever thought of extending the salmonid polyploid effort to commercial shellfish. The answer was we hadn’t, but thanks for the idea; we’d look into it.

Indeed, it turned out that very little had been done in the polyploidization of shellfish. In the literature was a fellow by the name of Longo who, in 1972 at Woods Hole, produced triploid embryos of the surf clam. A fungal metabolite, *cytochalasin B*, was administered just at fertilization which inhibited polar body extrusion in the dividing egg, resulting in triploidy. Longo went on to say that the bivalve shellfish would be the ideal animals with which to induce polyploidy for commercial production. The act of fertilization stimulates meiosis or the maturation division in eggs of mollusks; therefore, they would be amenable to ploidy manipulation. Further, shellfish are highly fecund, *i.e.*, up to 100,000,000 eggs per female oyster, thus no problem with progeny abundance. Also, since polyploidy might act to block gametogenesis, the huge egg and sperm production energy expenditure of each shellfish might be diverted to growth. Production hatcheries, (presently including four in Maine) would be available to take advantage of the development.

We decided to dabble in shellfish polyploidy, and everything we touched our hands to in the production of triploid shellfish turned to gold. First, graduate student Stan Allen came down to the hatchery at Walpole one weekend and repeated Longo’s early work, this time with American oysters. Stan only raised the animals for one day but found by chromosome counts that he indeed had produced 50 percent triploids. Stan graduated and went on to other work. A year later, we came to realize the potential importance of the work, and Stanley and I set about seriously to create and rear the world’s first brood of triploid shellfish, again American oysters.

Our experimental design was straightforward. We would administer *cytochalasin B* at 0-15 and 15-30 minutes post fertilization, thereby creating triploid oysters by blocking the first and the second meiotic division. The first group might perform better because they would be more genetically diverse since the entire homologous set of female chromosomes would be retained. The polar body released in the second meiotic division was merely a replicate of the female set remaining after the first meiotic division. A third group of untreated diploid siblings served as our controls.

Our troubles in properly evaluating the experiment began to mount. Happily, we found by chromosome cell counts that about 60 percent of our treated animals of both groups were indeed triploid. However, the three groups grew differently right from the outset. This might have been the result of ploidy manipulation or just as possibly could have been a subtle tank effect. Slight differences in handling of the groups very early in their lives could have resulted in the later growth differences that we were seeing. No scientific papers here.

After two years we were about to throw up our hands and go on with more sure but mundane research when we had a great brainstorm. We indeed had a valid experiment: our true controls were the 40 percent of the animals within the cytochalasin-treated groups which remained as diploids. These diploids were treated identically to their diploid siblings because in fact they remained as mystery animals within the groups from the point of fertilization onward. We needed to develop a method to determine the ploidy of a large number of shellfish using a method which didn’t kill the shellfish. Stan Allen again came to the rescue; he had been hired back as a research associate to work on a National Science Foundation funded project.

Blood cells were drawn from adductor muscles of the oysters, the nuclei stained for DNA density and the cells sent through a cytofluorometer in the Jackson Laboratory at Bar Harbor. The results were unequivocal as an indicator of ploidy in individual oysters. Preserved blood samples were sent from 400 coded numbered oysters, and results came back as to which animals were diploid and which triploid.

The resulting diploid and triploid size frequencies are most instructive. The meiosis I triploids were 40 percent larger by volume than their within-group diploid siblings. The meiosis II triploids did not grow faster than their diploid siblings. We checked the isozyme diversity of the animals and concluded that it was the increased genetic diversity that we created in the meiosis I triploids, rather than triploidy per se which produced the performance
gains. The really practical value here is that with a single manipulation we had a performance gain of 4 percent and, moreover, we knew the mechanism producing the gains. See photo page 35.

The work with triploid shellfish now was diversified and had indeed blossomed into something with commercial potential. A graduate student, Christina Tabarini, produced triploid bay scallops and found that the triploids were sterile. The adductor muscle, the part we recognize at restaurants, was 80 to 90 percent larger in the triploids because it is a glycogen storage site. The energy not used in gametogenesis conveniently goes to muscle weight. More recently we have produced triploid soft-shelled and hard-shelled clams and are busy evaluating these with particular regard to altered energy budgets and performance gains.

Stan Allen is now a Ph.D. student at the University of Washington and is experimenting fulltime with shellfish polyploidy. The main commercial species there is the Japanese oyster which is unmarketable in summer because the animal is in a reproductive state. Stan has now produced a neutered triploid Japanese oyster and the west coast hatcheries are gearing up for its production. All of this came from an original chance suggestion that, because of research logistics, we were able to pick up on. It had very little to do with our research emphasis at the time but a great deal to do with it now.

BIOL GICAL FOULING CONTROL
A chance situation produced another positive advance. Part of a shellfish hatchery operation is the outdoor nursery phase in which seed shellfish are placed in rafts with stacked, screened trays. A major expenditure is prevention and removal of fouling animals, barnacles, mussels and algae, which clog the mesh and smother the seed shellfish. In March Sam Chapman and I were tending our juvenile, overwintered, European oysters which were in stacked, screened trays. With one exception, the trays were uniformly covered with a rapidly growing set of 1 inch mussels and silt, with the oysters in a smothered condition beneath. A single tray from the middle of the stack, however, was as clean as could be: no mussel set, no silt, oysters as if they had been polished by a toothbrush. Chapman, our hatchery manager, looked at me and I looked at Sam, both suspecting a practical joke. A fast probe exposed the culprit. A small, 40mm rock crab (cancer irroratus) had been entrapped in the covered tray all winter and had foraged selectively on the mussel seed; even the tray mesh was picked clean. The oysters were silt-free because the crab had systematically turned them in search of food. We then did some real experimentation that summer and wrote a research note on biological fouling control in aquaculture. It turns out that this had never been done before: the culture of shellfish in enclosed spaces is relatively new and one must be able to retain the fouling control animal for it to be effective. Others have diversified the concept now, particularly in the use of browsing periwinkles as net tenders in shellfish nursery culture. Truely, this began as a simple-minded idea, but we recognized a good thing when we saw it and diverted our attention appropriately. See page 35.

NEVER SAY NEVER
Another chance happening is our development of hatchery techniques for the soft-shelled clam. Folklore has it that throughout its range from Virginia to Canada the soft-shelled clam is difficult, if not impossible, to condition and spawn in the hatchery. With so many other things to do, why deal with the impossible? Seven or eight years ago we had an independent-minded graduate student, John Stewart, who was funded by the Maine Yankee Power Plant to accomplish part of their environmental evaluation studies. John tested thermal tolerances of a number of easily spawned shellfish species. Then unaware of the difficulty with spawning soft-shelled clams, John proceeded to spawn and rear at least half a dozen broods of Maine soft-shelled clams throughout the spring. It happens that Maine clams are a bit different than the rest, retaining a good natural spawning condition throughout the spring months.

As the result of this finding and the subsequent work that it stimulated we are now the acknowledged experts in the hatchery culture of the soft-shelled clam. We have recently produced triploid soft-shelled clams. People seek us out for instruction; ask us to write chapters in books. We used the technology to learn more of the field ecology of Maine clams in a recent Sea Grant project. Now, thanks to Sam Chapman’s efforts, the spawning and rearing of clams has been incorporated in statewide coastal 4-H and secondary school biological activities. Thanks to John Stewart for being bumblebee enough to try hatchery rearing of the soft-shelled clam. It has the potential to be Maine’s next growth industry.

To say we’ve had good luck with these fortuitous developments is to put it mildly. In accomplishing research objectives outlined in a proposal, one must guard against letting the project, in effect, put the blinders on you. We always have an open eye for something new, the unexpected, and pursue it if warranted.

Just now, the Maine Agricultural Experiment Station is interested in a long-term effort to develop superior strains of American oysters for aquaculture. And follow the proposal outline we will: establish criteria for superior stock, culture and select progeny, cross and backcross the superior progeny, etc., etc. But I have a hunch that real advances will come from the little serendipitous occurrences which are bound to happen.
Diploid and triploid oysters.

Oyster trays with and without the services of a crab cleaner.
The biological oceanography of the sea floor lags behind its terrestrial ecological counterpart by a century or more, primarily because technological advances are required to enable humans to explore the ocean floor. In the mid-1800s, Charles Darwin became a successful biologist because he had the opportunity to visit new worlds and see a wide range of patterns in the distribution and abundance of organisms. His observations allowed him to speculate on the factors responsible for what he observed, and, in turn, his speculations became the beginning of modern ecology and evolutionary biology, fields that are now the foundations of myriad applied disciplines such as agriculture and genetic manipulation. Darwin's observations, and the observations of those who have followed him, have been limited to the events visible on land or from the surface of the ocean. The undersea realm is Earth's largest habitable area, but it is also the most difficult environment in which to work and about which we have the least firsthand experience. Submarine oceanography is in many ways our last frontier in the exploration of life on planet Earth.

The rich history of oceanography can be liberally traced back to well before Herodotus, the Greek geographer who drew the first map of the world in 450 B.C. The world map of Herodotus was the first charting of the world's oceans on which continued revisions and refinements have been made, and as such, it is the foundation of modern oceanography. As in most fields, scientific progress in oceanography was halting and slow at first, but with time it grew by leaps and bounds. In most cases, the leaps correspond to technological innovations such as inventions in navigational aids (the compass, accurate timepieces, sextants) and vessels.

The latter half of the nineteenth century was the golden age of oceanographic ships. Perhaps the greatest oceanographic vessel of that century was the H.M.S. Challenger which was built in 1871 by the British government on the recommendation of the Royal Society. It was staffed by six scientists and it was the first ship to contain extensive scientific laboratories for the study of physical, chemical and biological oceanography. Many other countries joined this period of exploration by constructing equipment and ships for oceanographic research. One such ship from Norway was constructed in the 1890s specifically to withstand being frozen in arctic sea ice so that studies in polar oceanography could be performed.

Despite more than a century of study of the water column and considerable efforts in sampling the bottom, it was not until 1930 that man, in the person of William Beebe, first entered the submarine realm. He was first to see the ocean from well below its surface by riding a sphere with a viewing porthole. Although he descended to great depths, he never saw the bottom, nor did he stimulate many immediate followers. In 1940 the first underwater camera was invented by Maurice Ewing. It was used during World War II to hunt for submarines but scientists had to wait until the 1950s to begin using it. Numerous refinements allowed special applications, but the technology remained primitive and the applications to science, beyond seeing something new, were limited.

To conduct research experiments in most cases requires a person's manual dexterity. The technological breakthrough that allowed this occurred during World War II. Two men, Cousteau and Gagnon, working secretly in Nazi occupied France, developed a means of regulating compressed air so that it could be safely inhaled by divers. The Nazis never learned about this development (which could have had enormous military application) and after the war this technology developed rapidly. During the 1950s the Self Contained Underwater Breathing Apparatus (SCUBA) became readily available to scientists and the general public. For the first time, people could visit and work untethered in depths of nearly 300'. Also for the first time, site-specific research and experimental manipulations were possible. Only then could first-hand observations be made about the submarine environment at the resolution enjoyed by Charles Darwin more than 100 years earlier.

The drawback to SCUBA diving is human physiology. Humans evolved on land and are adapted to the mixture of gases and pressure found at, or relatively near, sea level: one atmosphere. Every 33 feet into the ocean a diver descends, pressure increases by the equivalent of that found at sea level. At sea level a diver is experiencing one atmosphere of pressure; at 33 feet, two atmospheres, and at 66 feet, three atmospheres and so on. With increased depth, some of the harmless gases found in air become intoxicating or poisonous. Nitrogen in particular has a narcotic effect called nitrogen narcosis and is jokingly referred to as martini's law. This law states that every 50 feet of descent is the equivalent of one martini and judgment
is impaired accordingly. In addition, nitrogen gas, which comprises 70 percent of air, slowly enters the body during a dive. While under pressure the gas remains in solution, much the way carbon dioxide gas remains dissolved in a carbonated beverage while its cap is on (shake it up: no bubbles). When a diver surfaces too quickly, the external pressure on the body is released rapidly, and the nitrogen gas bubbles out of the tissues (as if the cap is removed from a warm and shaken carbonated drink: an explosion of bubbles). These bubbles commonly lodge at nerve connections, particularly around joints. In severe cases, bubbles form in the spinal column causing intense pain that doubles a person over: an extreme symptom of the bends.

The perils of the deep are minimized by SCUBA diving tables that tell the diver how long to stay at any given depth. The shorter and shallower the dive, the safer. Since scientific studies require considerable time, most are conducted in relatively shallow water. Working depths can be increased by breathing a mixture of gasses that are harmless under pressure (i.e., no nitrogen). Mixed gas diving is prohibitively expensive and complicated for most researchers.

To increase the time divers can work at depth, saturation diving was developed. This involves living underwater, at pressure, for extended periods of time. If a scientist needs to work at 100 feet, he simply lives at 100 feet and the body saturates to that depth. As long as he does not surface, the nitrogen stays in the blood stream. Decompression is a long process that is done once at the end of the mission. Saturation diving extends the depths and duration for which scientists can work.

Even with saturation diving, unprotected SCUBA divers can only work the shallowest portions of the oceans. In the past decade, technological innovations such as pressurized suits, manned submersibles and remotely operated vehicles (ROVs) have become available to scientists for the first time. With this high-tech approach, researchers can work at whatever depths, and for nearly as long as they wish.

In recent years manned submersibles and ROVs have made dramatic discoveries resulting in the golden age of exploration of the ocean floor. Among the many exciting new finds within the past five years is the discovery of biological communities receiving their energy from hydrothermal, rather than solar energy; the worlds deepest plants (seaweed) were discovered; countless new species have been photographed and collected, and numerous archaeological prizes including the Civil War ironclad Monitor, and the luxury liner Titanic have been successfully located.

Among the diverse scientists at the University of Maine at Orono studying oceanography is a group focusing on the ecology of bottom-dwelling organisms. With the use of SCUBA, researchers are beginning to learn what kind and how many plants and animals occupy coastal Maine. As studies are conducted of who eats whom, complex food webs are unraveled and interactions understood. Over the past two decades of manned undersea research, much new has been learned, but endless questions remain. For example, lobsters are known to be abundant in the areas where kelp is abundant, but kelp stocks appear to be dwindling. Lobsters can eat sea urchins, and sea urchins can eat kelp, but does that not mean if the lobster population declines, urchins will be released from their predators, infest coastal waters and strip them of kelp? Questions such as these have yet to be resolved but without SCUBA technology this line of research would be impossible.

Research to determine energy budgets for coastal Maine are being pursued. Recently for the first time, giant kelp plants were enclosed in flexible chambers that capture the oxygen released by kelp during photosynthesis. Constant readouts record light and oxygen over periods of several days. Results indicate that kelp are more productive than previously suspected. Other studies show that much of the organic matter produced on the rocky shores of Maine leaves those zones and goes elsewhere. How much is produced, and its eventual fate, is another line of research. One study is examining if algal-eating worms are increasing their abundance locally in response to the presence of rotting detached seaweed. The possibility exists that the correlation between the lobsters and the kelp is one of food. Detached kelp is food for worms which themselves are food for lobsters.

Behavioral studies require the presence of observers. The University of Maine’s Sea Grant Program is supporting SCUBA research to determine if lobsters are attracted to, or avoid, lobster traps. For this, divers tagged hundreds of lobsters and monitored their daily movements within and around four 10 meter by 10 meter grids each partitioned into 100 one meter quadrats. Spinoff research has recorded new data on lobster habitat preference, activity patterns, homesite movement, population densities, sex ratios, size frequency and growth. Lobsters and other animals with affected behaviors in captivity must be studied in their habitat and thus require SCUBA diving.

To extend SCUBA studies to deeper and offshore environments, the University is spearheading a major research project that uses manned submersibles funded by NOAA’s National Undersea Research Program. University scientists and others throughout New England have collaborated on a five-year study to explore, in the tradition of the H.M.S. Beagle or Challenger, the benthic resources and productivity of the Gulf of Maine.

University submersible studies have discovered ancient submarine shorelines; mapped geological sediment and biological fisheries resources; studied offshore sediments,
and compared offshore ecosystems with nearshore ones in terms of energy flow, productivity, and predator/prey relationships.

Of particular note was the surprising find of an offshore submarine island with a biological community unlike any previously reported in North America. Conspicuous by their absence were lobsters, crabs and sea urchins, but more significant perhaps was the find of a species of kelp and a limpet snail which were unlike anything found in this region before. If these are new species (specimens are currently being studied by specialists) at least two possibilities exist:

- evolution on this small island is rapid and has caused a unique biota in a way analogous to that observed by Darwin on the small islands of the Galapagos;
- since the kelp at least has similarities to species found in Europe, this could be an isolated area with oceanographic conditions more similar to Europe (cold but low seasonal fluctuations).

Offshore in the central Gulf of Maine, the high seasonal temperature variations due to continental influence are minimized by the moderating effect of the ocean and by oceanographic water masses unique to this area. This offshore community of algae is also one of the deepest cold water plant communities in the world and extends the depth of primary productivity deeper than previously thought. Transplant manipulations are being conducted to determine the depth limit of this algae and its rate of growth along a depth gradient. These findings are only several months old, but they reflect the sense of discovery available technology brings to this line of research.

To determine similarities and differences on a global scale, comparative ecological studies of seaweed growth and role in the food web were conducted in the Caribbean. Since tropical water is clearer than that found in Maine, this study had to be conducted at greater depths. For this, saturation diving from the underwater habitat HYDROLAB was necessary. After receiving three days of training, Aquanauts begin their dive as they would any other dive except that they do not surface. Elaborate procedures have been devised to allow divers to stay down for extended periods of time while their activities are carefully monitored from the surface.

The saturation diving research involved simultaneously measuring and recording photosynthesis of three algal samples and light along a depth gradient of 0, 5, 10, 15, 30, 60, 90 and 120 feet. Simultaneously, measurements were made of the rates of herbivory at each station by using underwater time-lapse movie cameras focused at fixed locations.

In a second HYDROLAB mission, the distribution, abundance and rate of decomposition of larger seaweed were studied. It was learned that, unlike Maine where sea urchins quickly find and devour detached algae, the algae in the tropics remained untouched. The hypothesis was advanced that the intense risk of predation by swift predatory fishes found in the tropics make the featureless sand plains too dangerous for scavenging herbivores. Thus, herbivores remain on or near the reefs because in those regions of production they are safe from predators due to the abundance of hiding places and they are well-fed.

Manned undersea research is still in its infancy. With technological innovations in new computerized, miniaturized and robotized undersea equipment, it is possible there will be a time when human presence is not required for such studies. For today at least, this is an exciting time and perhaps the last time for scientists to explore life on earth with the unabashed wide-eyed curiosity and sense of discovery held by the likes of Charles Darwin more than 100 years ago.
Robert Bayer is Professor of Animal and Veterinary Sciences at UMO. He earned a Ph.D. from Michigan State University and M.S. and B.S. degrees from the University of Vermont. His graduate training was in animal nutrition and physiology, and he has spent the last ten years studying the many facets of lobsters and the lobster industry in Maine.

DIET DEVELOPMENTS FOR THE MAINE LOBSTER

by Robert Bayer

Historically lobster pound operators have considered the feeding of their lobsters an investment. Feeding adds some weight to the new (soft) shell lobster and should reduce cannibalism among other lobsters. Lobsters in a pound are usually fed salted herring at the rate of sixty pounds (one bushel) per thousand pounds of lobster. How often this is done depends largely on the water temperature which affects the lobster’s rate of feeding.

Herring used for pound feeding, however, varies in quality and availability. Availability may become more of a problem with Department of Commerce quotas on herring catch levels and potential limits on the amount of bait fish that can be imported from Canada. The quality problems with herring are oil content and occasional rancidity. The herring fed to lobsters cost a minimum of $8 per bushel in 1984, or $260 per ton. At 30 percent dry matter, this cost is approximately $856 per ton dry matter.
PRELIMINARY STUDY

Very little research has been reported on pound feeding of adult American lobsters. Preliminary dietary formulations were based on a study of the natural dietary intake of adult lobsters done at UMO. In this study a nutritional analysis was done on the contents taken from lobster stomachs. The ingested food was analyzed for protein, mineral, energy, lipid and amino acid contents. It was found that hard-shell lobsters consumed a diet higher in protein and energy (calories) than a soft-shell lobster, but the ratios of protein to energy were almost identical. Soft-shell lobsters consumed a diet richer in mineral content than hard-shell lobsters. This is probably an attempt to add these minerals to the soft-shell to speed mineralization of the new shell and may be a function of the common practice of eating the old shell.

The next experiments were conducted to further define the lobster’s nutrient requirements. These studies were conducted in either of two facilities. Field trials were conducted at a lobster pound (Hancock, Maine) through the cooperation of Mr. Herb Hodgkins. At this facility lobsters on each test diet were placed in individual wooden storage crates and either held in a floating lobster car or sunk in the pound itself.

Laboratory trials were conducted in fiberglassen tanks with closed circulating artificial seawater (Instant Ocean). Salinity was held at 30 ppm + 3 ppm and temperature was held at 18°C + 1°C. Tanks were equipped with a layered filter of synthetic sponge, activated charcoal and dolomite. These filters were able to maintain a proper pH level (7.0), and nitrifying bacteria in the sponges kept ammonia to minimal levels. Lobsters have a unique mineral metabolism: they must continuously build new shells after the old shell has been molted. Several studies were done to determine the mineral requirement of lobster.

Semi-purified diets with varying calcium-phosphorus ratios of 2.0, 1.0 and 0.1 were fed to adult lobsters held in storage crates at the lobster pound. Lobsters were placed on each diet and a group of lobsters was held as a starvation control. Lobsters were fed three times per week for six weeks. The lobsters were initially weighed at three week and six week intervals. Growth was determined as the change in weight over the six-week period. Semi-purified ingredients were used to insure an exact calcium-phosphorus ration (Ca/P).

Starvation controls lost weight over the entire testing period. Although all lobsters fed artificial diets gained weight during the first three weeks of feeding, by the end of the sixth week lobsters fed two of the artificial diets, with calcium-phosphorus ratios of 0.1 and 2.0, had lost weight and those fed the diet with Ca/P of 1.0 had gained significantly more than the other treatments. The results from these studies indicate that dietary Ca/P can significantly affect growth in lobsters and that equal amounts of calcium and phosphorus yield optimal growth.

Salt mixes containing salts of many minerals are a standard component of most animal and fish diets. An experiment was conducted feeding groups of lobsters diets supplemented with common salt mixes. Weight gain was compared with lobsters that received a diet with no salt mix. The diet containing no salt supported lobster growth equal to that shown by the lobster that consumed the salt mix supplemented diet. It appears that lobsters are capable of fulfilling their salt requirement through absorbing minerals from sea water.

Since lobsters appear to have a major mineral requirement to calculate the shell after molt, it was assumed that a mineral supplement rich in calcium and phosphorus would enhance shell mineralization. New shell lobsters were fed a basic unsupplemented diet or the diet supplemented with SO₄ calcium phosphate. There was no difference in growth rate in lobsters fed either diet.

EFFECT OF PROTEIN-ENERGY RATIO

Protein is usually the most expensive ingredient in a ration. Therefore, in formulating a diet to replace herring in pound feeding, it would be necessary to keep this ingredient at a minimum and still meet the requirement of the animal. Data from natural intake studies showed that while the percent crude protein in the diet changed with stage of molt, the protein-energy ratio remained constant for hard-shell and soft-shell lobsters. Therefore, studies were initiated to investigate the effects of protein-energy ratio on the growth of adult lobsters first, when protein varied in the diet, and second, when energy varied in the diet.

Lobsters in early premolt (hard-shell) states were selected for growth studies. Groups of lobsters were maintained on different diets varying in protein and energy. Each diet group was held in a recirculating closed artificial seawater system. Lobsters were fed three times daily at 8am, 5pm and 11pm for eight weeks. Growth was measured as the change in weight over an eight-week period.

Results from the protein-energy ratio growth study showed there were no significant differences in growth on any of the diets, but there are some interesting trends. When the protein level in the diet remained constant at 33 percent, best growth was obtained on the diet with the highest energy content: the lowest protein-energy ratio. When the energy content of the diet remained constant, best growth was again obtained on the diet with the lowest protein-energy ratio even though this diet provided the lowest percent protein (16 percent). It should also be noted that when the two best diets are compared, the diet
having both the higher protein content and the higher energy content resulted in the best weight gain. These data suggest the lobster is capable of good growth on artificial diets where total protein contributes only one-third of the total energy. However, the total caloric density of the diet also affects growth rate.

Juvenile lobsters of the fourth stage (4 mm carapace length) have a much faster growth rate than adult lobsters and require less space for dietary testing. Therefore, a special license was obtained from the Maine Department of Marine Resources to study dietary requirements of juvenile lobsters and compare the results with those from the adult studies.

Sixty fourth-stage lobsters were divided into three diet groups. Each group was fed the three diets with protein-energy ratios of 0.07, 0.11 and 0.13. Each group was fed three times daily for 30 days. Growth was determined as the change in air weight over the 30-day period.

Juvenile lobsters receiving a diet with a protein-energy ratio of 0.07 obtained significantly better weight gain than juvenile lobsters receiving diets with higher protein-energy ratios. As with adult lobsters, the results indicate that the protein-energy ratio can have a significant effect on growth. In addition, these results show that diet studies with juvenile lobsters will yield significant results faster than studies with adults. Studies of the diet requirements of juveniles can expedite and clarify the collection of data relating to lobster nutrition.

A practical diet for feeding lobsters in pounds, cars, and tanks was formulated based on the previous data. Flavor of the lobster meat as influenced by the diet was also a concern.

The objective of this study was to compare weight gain and meat flavor of lobsters fed synthetic diet versus a diet of herring. Salted herring scrap is the conventional ration fed to lobsters held in high density confinement in lobster pounds. The formulated synthetic diet was composed of fish meal (30 percent), brewer's yeast (10 percent), alfalfa (10 percent), kelp meal (3 percent) and wheat flour (47 percent).

Before the feeding trial began and after 48 days on the diet, the lobsters were weighed both suspended in water (SW) and in air (AW). The mean changes in wet weight were 16.0 g (SW), 22.4 (AW), and 6.8 g (SW), 11.7 g (SW), for lobsters fed the formulated diet and the herring diet, respectively. The mean change in weight for lobsters fed the formulated diet was significantly greater for both weight values.

For evaluation of flavor, live lobsters were cooked for 15 minutes in a steam-jacketed kettle containing boiling three percent sodium chloride brine which was freshly prepared for each of four replications. Four lobsters from each of the groups which had been fed on herring scraps or on the synthetic diet and eight lobsters harvested from their natural habitat were cooked at a time. The meats from the tail sections were cut into pieces, coded, and presented in a randomized complete block design, with four replications, to a sensory panel of 17 members. The panelists, who were experienced in assessing flavor qualities of foods, were asked to compare the flavor of each sample with that of a labeled, freshly-harvested reference standard which also was included as a coded control sample.

Scores of +3 (better than standard, large difference) to a −3 (poorer than standard, large difference) were assigned to the 7 point rating scale. The flavor of lobsters which were fed the synthetic diet (mean = −0.10) was rated equal to that of the coded control sample (mean = −0.06). Meat from lobsters which had received a diet of herring scraps, however, was judged slightly poorer in flavor (mean = −0.65) than both the freshly harvested control and the synthetic diet fed lobsters. These differences were significant at the 1 percent level of detection.

From the studies presented and discussed above, several conclusions can be drawn:

- Calcium-phosphorus ratios in artificial diets can affect growth (weight gain) in adult lobsters; a Ca/P of 1.0 gave best growth.
- No mineral mix is necessary in artificial diets formulated from conventional feed sources as long as the calcium-phosphorus ratio in the feed mixture is near 1.0.
- Mineral supplementation of artificial diets fed to soft-shell lobsters does not significantly affect weight gain in these lobsters.
- Adult and juvenile lobsters fed artificial diets with varying protein-energy ratios showed best weight gain on those diets with the lowest protein-energy ratios (0.07).
- Diet studies using juvenile lobsters resulted in growth data that were more quickly obtained and showed statistical significance when compared to the same studies using adults.
- It is possible to formulate an artificial diet from conventional feed sources which will result in growth as good as, or better than, herring under pound conditions. Such a diet is presently being fed in commercial pounds. See photos page 42.

Acknowledgments
The article summarizes the work of many people. They are Dr. Margie Lee Gallagher; Dr. James Rittenburg; Lorna Rittenburg; Dale Leavitt; Ruth True; Theresa Work; Martha Lunt; Herb Hodgkins, and William Barter. These studies were funded by Sea Grant and the Maine Agricultural Experiment Station. The lobster diet that evolved from these studies is commercially available from Lobster Products, Inc., Hancock, Maine.
This is a histological preparation of a lobster gill from a lobster infected with gaffkemia. Note the tetrad pattern of Aerococcus viridans, the pathogen causing the disease. The disease can be controlled by using an antibiotic-treated lobster feed developed by U. Maine's Robert Bayer.

Baby lobsters.

Marsh near Tenants Harbor, Maine.
THE MARSHES OF GLYNN

In a league and a league of marsh grass, waist high, broad in the blade,
Green, and all of a height, and unflecked with a light or a shade,
Stretch leisurely off, in a pleasant plain,
To the terminal blue of the main.
Oh, what is abroad in the marsh and the terminal sea?
Somehow my soul seems suddenly free
From the weighing of fate and sad discussion of sin,
By the length and the breadth and the sweep of the marshes of Glynn.

—Sidney Lanier

A WET DESERT
secrets of the salt marsh

by Gary M. King

Salt marshes are unique ecosystems that combine aspects of both terrestrial and aquatic environments. Salt marshes are distributed worldwide, but are most abundant in temperate to tropical regions with little natural physical disturbance. In the United States, salt marshes occur on the Atlantic, Gulf and Pacific coasts with the greatest areal coverage found along the shores of Georgia, South Carolina, and Louisiana. Expansive marshes are found in other regions, but in general these account for only a fraction of the total marsh habitat. Some limited marsh systems also occur inland along the shores of saline lakes but these too are quite small. Even though the extent of marsh in a given area may be small, marshes very often have significant local as well as global importance.

Salt marshes have long attracted poetic, commercial, and academic interest. Man has always turned to the sea for spiritual and intellectual pursuits, so it is natural that salt marshes have been the focus of much attention. These systems represent a remarkable transition zone between terrestrial habitats on the upper end of the high tide line and truly marine habitats below the low tide mark. Since salt marshes are not quite terrestrial or marine, the organisms that inhabit them must have adaptations suited in part for both styles of living. The adaptations required for successful colonization have limited the diversity of marsh inhabitants, yet those plants and animals that are present are often found in high densities and are highly productive. In fact, marshes are among the most productive habitats per unit area that are known. The annual accumulation of plant biomass in marshes often exceeds that of the most intensively farmed crops and is comparable to the productivity of sugar cane in the tropics. Though salt marsh plants are not currently harvested for human use, marsh production has often been considered an important food resource for the juveniles of many commercially important fish and shellfish that inhabit the estuaries on which marshes border. Some have even described marshes as nursery grounds for a number of fish, crabs, and shrimp.

The high productivity of marshes has not only been of commercial interest. There has been substantial debate and research during the last three decades in an effort to understand why marshes are so productive and what happens to their plant biomass. The questions concerning
productivity arise because marsh soils can hardly be considered fertile ground for typical plants. Marsh soils generally contain hydrogen sulfide (a potent toxin), no oxygen, and high concentrations of salt. And although the soils are usually waterlogged due to frequent flooding by tidal activity, the presence of salt means that the plants live in a virtual desert from the standpoint of the availability of fresh water. That some plants can grow, let alone flourish, in such an environment obviously requires highly specialized adaptations. The adaptations found in salt-marsh plants are in fact typical of those found in plants from arid regions including deserts. Questions concerning the fate of plant biomass are important since relatively little of the annual plant production is consumed by grazing animals. Possible fates for plant tissue include burial, export to the surrounding tidal waters, or loss as carbon dioxide ($CO_2$) during decomposition by microorganisms. Each of these possibilities has important implications. For instance, the burial of plant matter may serve as a mechanism for coal formation over geological time scales; export of plant biomass may serve as a food source for commercial fisheries offshore; losses of $CO_2$ represent a means of recycling nutrients. Answers to the above questions are clearly needed to assess not only the behavior of the marsh as an ecosystem, but to provide the insights necessary for wise management of coastal wetlands.

My own research has been concerned with problems of both the production and fate of marsh plant biomass. Of particular interest has been the regulation of Spartina alterniflora production. S. alterniflora, the salt marsh cordgrass, is perhaps the most abundant marsh grass in North America. It is especially abundant in mid and southeast Atlantic and Gulf Coast marshes where it often occurs in vast marine prairies that are hundreds to thousands of acres in area. Cordgrass also occurs northward into Canada and is abundant in a number of marshes in Maine.

One characteristic of this robust plant is that it is most productive along the edges of the many tidal creeks that meander through salt marshes (see photo p. 42). Plants on the creek banks very often reach a height of three to six feet while plants in the more interior regions of the marsh are usually one foot or less. The reasons for this height and production gradient have remained elusive in spite of years of research by dozens of scientists. In part, this has been due to the search for a single, simple explanation. Unfortunately, it now appears that no one variable or parameter is adequate to explain the pattern of cordgrass production. Instead, a number of variables seems to control plant growth via complex but elegant interactions among plant metabolism, soil hydrology, soil chemistry, and soil microbiology.

In one ongoing study, I am collaborating with a faculty member of the University of South Carolina in an effort designed to examine some of the complex interactions mentioned above. This study is funded by the National Science Foundation and involves the use of experimental sites in a marsh at Georgetown, South Carolina. We are also using artificial marshes contained in a series of 10 3' by 3' Plexiglas chambers. We have manipulated nutrient regimes in both the field and artificial marshes and are monitoring plant production, soil chemistry and soil microbiology on a seasonal basis. Our initial objective was to determine whether toxic hydrogen sulfides present in the marsh soils were involved in controlling plant production and what variables in turn controlled the presence of hydrogen sulfide.

Though the study is only two years old, some clear patterns are beginning to emerge. First, it is evident that the availability of nitrogen for plant growth is a critical factor in determining production. Additions of nitrogen result in vigorous growth relative to unfertilized controls. However, nitrogen alone is not the key element since substan-

![Figure 1](image_url)

Depth profiles of Spartina alterniflora roots and bacterial sulfate reduction in soils of a Massachusetts salt marsh. Note the rapid decrease with depth for both variables. These data are typical of many salt marshes. Bacterial sulfate reduction is the major source of hydrogen sulfide ($H_2S$), a potent toxin, in salt marshes.

tial concentrations of nitrogen (as ammonia) are actually present in the marsh soil. It appears that the ability of plants to utilize this nitrogen is limited by other variables. The addition of an iron-containing mineral also stimulates plant growth. Since iron is not a limiting nutrient in salt marshes, the effect of added iron must be due to its role in nonnutritional processes. One possibility involves the precipitation of hydrogen sulfide to form the black coloration common in many soils devoid of oxygen. Precipitation of hydrogen sulfide would be beneficial because it is highly toxic and could well decrease the ability of plants to use nutrients. The increased growth we have observed after the addition of iron is consistent with the notion that hydrogen sulfide normally decreases growth by inhibiting nutrient uptake; removal of hydrogen sulfide by iron relieves the inhibition and allows greater utilization of ambient nitrogen. The stimulation of growth by nitrogen fertilization noted above can occur even when hydrogen sulfide is not artificially decreased as a result of the mass action effect; increased nutrient concentrations increase rates of nutrient uptake.

An additional factor limiting plant production is tidal water salinity. At salinities approaching seawater values, marsh plants require a substantial amount of nitrogen in order to survive. The presence of salt in seawater decreases the amount of fresh water plants can use. In this regard, seawater is analogous to a desert; in fact, marsh plants possess some of the same mechanisms as desert plants to conserve water. One such mechanism involves the use of nitrogen. If nitrogen availability is limited, then salinity can play an important role in determining production. To further exacerbate matters, high salt concentrations can directly decrease the uptake of some nutrients, such as ammonia, and exert effects similar to those of hydrogen sulfide.

Other parameters that are important in controlling plant growth include soil hydrology, soil oxidation, and the production of hydrogen sulfide by soil bacteria. Each of these parameters, along with salinity, nitrogen, and iron regimes forms a complex interaction that is responsible for determining the distribution of plant biomass in salt marshes. By selective manipulations of some of these variables in field and experimental marshes, it is possible to determine the relative importance of a given variable and the nature of the interactions that occur. The models currently being developed and tested should significantly increase our understanding of the dynamics of marsh plants, not only in South Carolina, but in New England marshes as well.

Other salt marsh research conducted in my laboratory involves field sites in Maine, Massachusetts, South Carolina and Nevada. Work in these sites is designed to determine the controls of methane production and methane fluxes to the atmosphere. Methane, the major constituent of natural gas, is a trace component of the atmosphere. But in spite of its low concentrations, methane plays a significant role in the chemistry of the atmosphere and in the heat budget of the earth. In fact, the predicted increases in atmospheric methane over the next 50 to 100 years are expected to contribute to the global warming that will result from the greenhouse effect of increases in carbon dioxide.

Earlier work done in Georgia salt marshes indicated that marine environments may contribute to atmosphere methane. Present studies suggest that the source of that methane is from compounds produced by a variety of plants and animals as a response to living in a saline environment. These compounds are subsequently converted by bacteria in salt marsh and other marine sediments to methane. This process explains the presence of methane in environments where it is not otherwise expected. Collaboration with colleagues in the U.S. Geological Survey indicate that methanogenesis in inland saline marshes may occur via a similar mechanism. Collaboration with colleagues at the Woods Hole Oceanographic Institution (WHOI) has also identified salt marshes as significant sources of a major sulfur-containing gas, dimethylsulfide. Dimethylsulfide, like methane, is a trace gas; even so, it is a critical component of the global sulfur cycle. Researchers at WHOI have shown that dimethylsulfide is probably formed in salt marshes from compounds similar to those from which methane is derived.

Ongoing studies, which are funded by the National Aeronautics and Space Administration (NASA), involve multisite comparisons in a variety of marshes on the east coast and an inland system in Nevada. Our ultimate goal is to correlate emissions of gases, such as methane and dimethylsulfide, with parameters (for example, plant biomass) that can be measured from satellites using remote sensing techniques. Successful correlations would allow global estimates of gas fluxes from wetlands based on determinations of the areal distribution of wetlands via satellite imaging. Global estimates of gas fluxes are necessary for understanding the dynamics of the atmosphere and the extent of temperature changes on the Earth’s surface due to increased concentrations of trace gases.

In summary, salt marshes are extraordinary ecosystems with impacts that reach far beyond the high and low tide boundaries which define the areal extent of the systems. The distribution and activities of the plant, animal, and microbial populations within salt marshes are controlled by a variety of complex physical, chemical and biological interactions. Analysis of these interactions provides valuable insights for understanding not only the behavior of salt marshes but other marine and terrestrial ecosystems as well. Likewise, analysis of gas formation in salt marshes provides important models for understanding the dynamics of several critical trace components of the atmosphere.
MAINE MARSHES

by George L. Jacobson

Maine’s geologically variable and highly convoluted coastline harbors large numbers of small marshes which fringe tidal creeks and fill in countless indentations in the rocky coast. Recent studies by Dr. George L. Jacobson and Heather A. Jacobson in cooperation with Dr. Joseph P. Kelley have produced the first careful measurements of the areal extent and the geographic distribution of these marshes along the coastline. They have found that almost one-fifth of Maine’s 6000 kilometer coast is covered by these intertidal ecosystems. A majority of these occur south of Penobscot Bay, and except for a few well-known exceptions, most of the 3070 marshes are less than 10 hectares in area. Only a few marshes in southern Maine approach the scale of the huge marsh systems of Georgia or the Carolinas. Maine marshes constitute approximately half of the total marsh area bordering the Gulf of Maine. The extent to which they contribute to productivity in the nearshore waters of the Gulf of Maine has yet to be determined, however. Studies completed by Dr. Robert L. Vadas of the Department of Botany and Plant Pathology have shown that Maine’s marshes are comparable in productivity to the marshes of southern New England; the key question remains whether the biomass produced in a marsh moves into the marine system in significant quantities.

As part of their work, Jacobson and Jacobson have completed detailed field studies of 18 undisturbed marshes spaced along the coast between Kittery and Lubec. At each site they have completed botanical surveys designed to reveal the nature of the marsh zonation and the abundances of the species present. Their results show that Maine’s salt marshes vary greatly from site to site depending on geology, tidal amplitude, and other environmental factors, and that these marshes are different from those of southern New England and the southern Atlantic coast. The photograph on page 42 shows a salt marsh near Tenants Harbor, with characteristic zonation from low-marsh to high-marsh. Data collected from several transects across this marsh are summarized in the corresponding figure. The upper section shows schematically how the vegetation zones occur along the slope up to three meters above the tidal creek; the lower panel shows changing abundances of several important plant species along the same transect. This marsh is similar to many that occur along tidal creeks of coastal Maine.

George L. Jacobson, Jr., is Associate Professor of Botany and Quaternary Studies and until recently served as Acting Director of the Center for Marine Studies at UMO. He earned his Ph.D. at the University of Minnesota, and his research interests focus on plant ecology and terrestrial vegetation dynamics of eastern North America during the past 15,000 years.
The meaning of the Cooperative Extension Service is contained in its name: cooperative, interdisciplinary professionals reaching out to provide services to the citizens of the state.

**MYA ARENARIA**

return of the clam

by Devon Phillips

A quiet revolution is underway in Wells. Some of the area's finest citizens—teachers, scientists, even some of the brightest young people—are conspiring against considerable natural odds to reestablish the harbor's soft-shell clam population.

On a sunny day, you might have to squint to see evidence of the uprising. But it's there, dipping and bobbing on the ripples in a sheltered cove near the main harbor: 30 trays filled with a half-million specially cultivated juvenile clams, *Mya arenaria*.

Eagerly watching the clams' development are the Cooperative Extension Service, the Department of Marine Resources, an assortment of educators, the Wells Clam Commission, a couple of 15-year-olds from the local high school, and others, all of whom have worked since last spring to nurture the tiny bivalves to a size suitable for seeding in the local mud flats.

For if this effort succeeds, Wells could again become the clammers' mecca it was 35 years ago. Back then, according to retired animal pathologist and Wells Clam Commission member Bob Pirozok, there were clams aplenty for both recreational and commercial diggers. Pirozok himself recalls *digging to my heart's content in Wells mud* during vacations from his teaching post at the University of Connecticut.

But then Wells' clam harvests began to decline, the reasons given as several as the scientists who studied the problem. Pirozok blames a combination of overdigging and an explosion of green crabs, which prey upon clams. On the other hand, Sam Chapman, an aquaculture specialist at the University of Maine's Darling Center in Walpole, suggests other explanations.

No one knows why the clam population declined in Wells, he says. *It could have been a matter of biological cycles or maybe overfishing. Or maybe, Chapman offers, siltation simply changed the profile of the Wells estuary over time, affecting clams' ability to set and grow in the area.*

In any case, as often happens, humans were no help. Until 1982, when the town built a sewage treatment plant, some of Wells' raw human wastes inevitably wound up in the harbor. About 12 years ago, the Department of Marine Resources, alarmed by the amount of coliform bacteria in the water, forbade clammers in Wells. The new sewage plant has reversed all of that, and yet, for whatever reasons, clams still seem to be struggling for a foothold in the estuary. Although last spring's harvest was bountiful, it yielded mostly eight-to ten-year old clams in the three-inch size range. Diggers turned up few of the younger one-inch variety, and scientists say that bodes ill for harvests next year and beyond.

Fortunately for Wells, other Maine coastal communities have faced a similar problem, and at least one has successfully fought back. Ten years ago, people in the downtown community of Jonesboro wanted to know why the clam population on their mud flats was dwindling. Most of Jonesboro's 560 citizens dig, shuck, deal, retail, and/or ship clams for a living, so the common weal depends heavily on an abundance of the creatures.

In response to the townspeople's concern, the Cooperative Extension Service sponsored a clam survey in the Jonesboro/Roque Bluffs area. The findings proved the locals' suspicions: the clam population was indeed slipping, probably due to a combination of overdigging and natural factors. From this survey, the first ever written down in the history of the region, Extension agents, with input from the diggers themselves, decided to solicit further study of the clams and their mud flat environment in Jonesboro.

*Devon Phillips is information and publications editor with the Cooperative Extension Service at the University of Maine at Orono.*
In 1980, the town’s Clam Committee and Planning Board sought help from researchers at the Darling Center and Maine’s Department of Marine Resources. With support from the University of Maine’s Sea Grant program and the state’s Coastal Zone Management Program, experiments were set up on the mud flats to determine what could be done to recruit young clams to the flats.

As a result of those experiments, 30 young people in Extension’s 4-H program, ages nine to 17, set up their own clam hatchery. Under the guidance of the Darling Center’s Chapman, the volunteers spawned nearly a half-million clams and incidentally gained a much improved understanding of bivalve biology.

In 1983-1984, baby clams reared at the 4-H hatchery were transplanted to the Chandler River flats. With that success, the hatchery promptly expanded its line to include scallops and mussels. Extension marine project assistant Brian Beal designed field demonstrations to monitor the effects of baby clam, scallop, and mussel densities, season of planting, and type of substrate or soil used on the growth and survival rates of the mollusks.

All in all, Chapman recalls Jonesboro was a very successful project—the kind of work where you go home at night knowing you’ve done a good job. And a good job it was, as last summer’s bounteous clam harvest demonstrated.

In Wells, as in Jonesboro, citizens weren’t about to say goodbye to clamming—not without a fight. From time to time, the Clam Commission and others with fond memories of better days on the flats would try to seed the local mud using tiny two-millimeter seed clams, scattered like grass seed, Pirozok explains. About 75 percent of these clams were either lost to the tides or snapped up like hors d’oeuvres by the crabs.

Then new hope: At a conference on Increasing Clam Harvests in Maine, sponsored last January in Brunswick by the Extension Service, Pirozok learned of Jonesboro’s successful pro-clam effort and decided it merited a try in Wells. Back home, he contacted York County Extension agent Joe Blotnick for help in involving young people in reseeding the Wells flats. After recruiting a few teachers for the cause, Blotnick invited Chapman to give a slide show in June for local officials, teachers, and students on the art and science of clam hatching. What Wells needed, everyone agreed, was a large-scale seeding of clams large enough to survive the tides and the predators, combined with an aggressive campaign against the greediest of the predators, the green crab. To expedite matters, Chapman agreed to culture some 500,000 baby clams in his laboratory at the Darling Center for later seeding in Wells.

By controlling water temperatures, Chapman says, scientists can culture clams in an artificial setting at a rate two to three times faster than occurs when the process is left to Mother Nature. To start, Chapman digs a broodstock of about 60 large clams in mud flats near the lab. Back at the Center, he scrubs the shells with a bristle brush and places them in a three-foot-square tray in filtered seawater. A half-hour later, algae is added to the water, causing the clams to increase their pumping. (Like all bivalves, the clam is a filter feeder, sucking seawater in through one tube, its siphon, or neck, extracting the algae, and expelling the water through another tube in the siphon. The presence of food—algae—stimulates this action.)

Next, Chapman warms the water to 18-20 degrees C. The male clams—thinking it’s the kind of warm summer day when clams spawn in Maine, the scientist explains—release inside their shells billions of sperm, which are washed into the water by the current. Pheromones released with the sperm stimulate further sperm release and cause females to release their eggs.

At this point, Chapman puts the females in a separate tank. After rinsing the eggs away from the females, he begins adding sperm a few milliliters at a time. This gradual introduction of sperm helps to prevent polyspermy, an abnormal condition in which a single egg is fertilized by more than one sperm.

Wells High School students Alicia Richard and Laura Tufts clean clam trays of built-up algae and silt at town wharf. (Photo by Dan Gail, York County Coast Star.)
Another 30 minutes later, Chapman examines all the eggs, each about 60 microns in diameter, under a microscope for signs of fertilization. (Minutes after penetration by a sperm, the egg extrudes a bit of extranuclear material, which appears under the microscope as a bubble attached to the egg.) If the eggs appear well fertilized, they are diluted to about eight to ten eggs per milliter for incubation in a 400-liter tank. Of the roughly four million eggs thus incubated, the scientist expects 70 to 75 percent will grow to become larvae.

The diluted eggs are then placed in a larval tank. Conditions in the tank are a junior clam's paradise: filtered seawater warmed to 24 degrees C., lights to keep a feast of algae growing steadily, and an aerator at the bottom of the tank, which jostles the eggs to minimize the growth of bacteria. Twenty-four hours of such coddling produces tiny, swimming trophophore larvae with heart, cilia, digestive tract, and shell; another day and night, and the babies have begun to feed.

In the next 12 to 14 days, the larvae will mature into juvenile clams, about 300 microns or one-seventy-fifth of an inch in length. The juvenile clam has lost its cilia and no longer swims; rather, moving along surfaces by means of a muscular foot, it seeks a settling place, trailing the fine, sticky byssal thread by which it will attach itself.

At this stage in the wild, Chapman says, the young clam is fair game for everything, including glass shrimp, mummichogs, moon snails, even other clams. A little later, the larvae may fall prey to flounder, green and horseshoe crabs, ducks, and raccoons.

Life in a laboratory tank is, by contrast, considerably kinder: no predators, and an abundant—if boring—diet of specially grown isochrysis gabana, a Tahitian species of phytoplankton. In the lab, Chapman says, you feed by the numbers. Half a million juvenile clams will consume about 15 gallons of algal culture per day.

After five weeks in the tanks, the youngsters Chapman cultured for the Wells project were delivered to Wells and placed on fine screens inside six fiberglass trays on the town wharf. For several weeks, a machine constantly pumped unfiltered seawater over the clams. Local high school students Alicia Richard and Laura Tufts worked with Pirozok to maintain the trays, cleaning out algae and silt buildup once a week and sorting the clams according to size using meshes of varying densities.

In September, when the clams had grown too large to wash through an ordinary window screen, Pirozok, Richard, and Tufts transferred them to floating trays, strung together in the harbor (later the trays were moved to a quieter cove, shared by a restaurant's lobster tanks). Periwinkles were added to the trays to serve, Chapman said, as miniature bulldozers, consuming excess algae that would otherwise accumulate on the clams.

Once the clams measure three- to five-eights of an inch, sometime around mid-November, the mud flats will be disk-harrowed and the carefully nurtured progeny at last seeded, about 100 per square meter. Already sexually mature, the seed clams that survive will be ready to reproduce by summer. Clams that withstand predators, disease, and environmental extremes may live ten to 12 years.

Meanwhile, to help ensure that the seed clams—and next summer's offspring—get off to a good start in their new home, Pirozok spent his summer busily trapping the predatory green crabs. By November's seeding, this year's crab crop will be on the wane, driven into hibernation by colder temperatures. In warmer months, however, the crabs flood in with each tide, devouring clams of all sizes but especially the smaller, younger individuals. The crab's strategy: Dig into the estuary's sandy bottom until you find a clam; then pick at the seam of the clam's shell until you can force the shell open and consume the occupant.

To try to block the crabs' access to the clam flats, Pirozok deployed more than two dozen traps baited with haddock racks donated by a local fish market. This year, Pirozok reports snaring 62,000 crabs, which were subsequently destroyed and taken to a landfill. The trapping program will probably have to be repeated every year if clams are to return permanently to the flats in numbers sufficient to allow good recreational clamming, Pirozok says.

But reviving the flats for clam diggers is but one goal of the Wells project. Cooperative Extension's Blotnick, and Jack Ney, a marine science instructor at Southern Maine Vocational Technical Institute, are working to make reseeding and maintaining the flats a hands-on educational project for elementary through high school science classes. Last fall, a three-hour teachers' inservice training workshop entitled Clams in the Curriculum: A Natural School and Community Project introduced 30 teachers from Wells, York, Alfred, and surrounding communities to shellfish biology and the curriculum opportunities inherent in the project.

Particularly with the proposed development of a clam hatchery at Wells Harbor next spring and the schools' proximity to the harbor, Blotnick sees the possibility of a dynamic natural classroom in which elementary grades could study basic clam biology and high school students could pursue data-collection, research, applied science, and community-action projects. In addition, through working with clams, a $11.5 million industry in Maine and the state's third most important fishery, the students could also gain insights into the economics of a major natural resource. For me, Blotnick comments, the beauty of this project has been in involving kids . . . and talking with teachers about ways to bring science to life.
One teacher who has leapt into the project—and the mud—with both feet is Pam Fisher, a Wells High School chemistry teacher who also is part-time director of a program for 35 to 40 gifted students including summer clam-tenders Richard and Tufts. Fisher views the clam project as a good opportunity for the sort of long-term task commitments she says bright, motivated teenagers need. Fisher herself helped organize the October teachers’ workshop and looks forward to involving students in the development of the Wells clam hatchery. Even before that time, students may start work with the Clam Commission to develop a program for monitoring the seed clams’ rate of survival.

Seen as a whole, then, the Wells Clam Project should be a lesson to those who think that school is all book learning, or science all laboratory work, or clams just shellfish. For in Wells, the lowly, unprepossessing clam has proven itself a powerful symbol, a cause strong enough to lure school out of the classroom and science out of the lab. Denizen of a muddy zone that is neither land nor sea but something of both, the clam now lies at another interface: the meeting place of science, education, and nature. How wisely we humans tend that fertile zone may determine the fate of the clam in Maine waters.

**CES: commitment and action**

The Cooperative Extension Service (CES) is a member of the University of Maine’s Marine Advisory Sea Grant Cooperators Network, an innovative coalition of organizations, institutions, and agencies in Maine bearing responsibility for marine education. As such, Extension has led efforts to improve the quality of life all along the state’s 3,500-mile coastline. For example:

*Recently, Extension, the Department of Marine Resources, and Sea Grant brought together shellfish harvesters, dealers, municipal shellfish committees, and specialists for a first-of-its-kind Maine Shellfish Conference in Rockport. Participants explored the latest information on marketing, leasing, pollution, shellfish research, prevention of hypothermia, and other topics.*

*Extension has provided leadership in the development of bylaws for a statewide association of harbor masters. The group seeks to foster communication, education, and effective management of harbor resources among Maine’s 107 coastal communities. Also, CES has published a Guide for Harbor Management for harbor masters, selectmen, and harbor committees.*

*Since 1983, more than 1,500 schoolchildren have participated in the Knox-Lincoln County Extension/Tanglewood 4-H Camp program, Connections to the Forest and the Sea. Through this hands-on program, young people and their teachers have gained a deeper appreciation of the ecology of Maine’s forest and tidal areas.*

*More than 1,000 campers in the past decade have participated in Extension’s three- and four-day excursions to Vaughn’s Island in Cape Porpoise Harbor. According to Joe Blotnick, York County Extension agent, the experience has helped youngsters learn about coastal ecology and the development that threatens it. Campers also learn no-trace camping skills, and clean up after less considerate visitors.*

*Life on Maine’s Tidal Rivers—An Approach to Estuarine Education, an Extension publication, focuses on life on a saltwater farm. The report is a collaborative effort between CES, the Freeport Historical Society, and Maine Audubon.*
One program that has greatly stimulated marine research in the State of Maine goes by the acronym EPSCOR which stands for the Experimental Program to Stimulate Competitive Research. Funded by the National Science Foundation as a means by which to enhance the scientific community in Maine, this program has achieved much in the field of marine sciences over the past five years. Researchers at both UMO and the Bigelow Laboratory for Ocean Sciences have participated in this effort which has recently led to the development of even closer collaboration in the recently formed ARGO Maine Project (Associated Researchers on the Gulf of Maine).

A major thrust of the EPSCOR was in the field of benthic oceanography (from the Greek benthos - of the bottom). A group of six EPSCOR scientists comprise the Maine Benthic Oceanography Group and spend most of their time mucking about in the mud. This necessarily upward looking group has developed what is likely this nation’s first coherently planned benthic group, and it is clearly paying off in terms of scientific productivity and national visibility for marine sciences in Maine. Four members of the group are located at the University, representing four different departments: Botany, Microbiology, Geological Sciences and Zoology.

The research theme for the benthic group is the factors that affect biological productivity in the sediments. This environment is a particularly important one for Maine, because the major fraction of fisheries landings consists of fish that live or feed at the bottom of the ocean. Lobsters and clams come quickly to mind, of course, but don’t forget all those other shellfish and bottom dwelling finfish, such as flounder and cod. These fish generally feed on smaller animals in the sediments, which in turn often feed on organic matter associated with the mud.

This primary theme can be further divided into three subthemes. First, what kinds of organic matter are delivered to the sediments, and how are they delivered? Does the sediment ecosystem live completely off the phytoplankton in the water column (the small one-celled plants that account for most of the plant production in the Gulf), or are other plant sources like seaweeds and sea grasses also important? What oceanographic factors control the sites to which this plant material will be delivered; for example, how far out to sea can seaweed fragments be transported? Second, how does the benthic community, the animals and bacteria, respond to these inputs of organic matter? For example, what is the shape of the food chain which brings the delivered organic matter up to the level of fish? How important are the bacteria, and the myriad forms of small animal life that feed on sediment grains? How fast can the sedimentary mill grind, in terms of rates of metabolism in different parts of the Gulf or at different times of the year? Third, how does the sediment ecosystem in turn affect the water column ecosystem? We know, for example, that metabolism in the sediments regenerates nutrients in the same fashion as a backyard compost heap, but we don’t know the importance of this regeneration in transferring the resulting fertilizer back to the water column where it can be best utilized for more plant production.

The products of the research from this group have important uses for other fields, as well as biological productivity. Sediments act as an important zone for pollutant accumulation; a better understanding of the sediments as an ecosystem will help us predict the fates of pollutants introduced to sediments. The biochemical studies of metabolism in the sediments provide information on biochemical properties of other systems; for example, there are fermentation reactions in the sediments that are very similar to those used in commercial fermentations. Animals and bacteria have very noticeable effects on the way sediments themselves accumulate, which leads to fruitful interactions with geologists.

Many collaborations have sprung from the construction of this group. All of the members concentrate their research on the Gulf of Maine and its associated estuaries. Most are involved with the submersible program, using the Johnson Sea-Link to add new technological possibilities to work already begun in shallower waters. Several participated in an expedition to apply techniques developed in Maine to a tropical ecosystem in the spring of 1985. This type of geographical expansion is vital to the maintenance of a broad perspective of the work being done in Maine.

Lawrence M. Mayer is Associate Professor of Geological Sciences and Acting Director of the University of Maine Sea Grant Program. He earned his Ph.D. in geology at Dartmouth College, and his research interests include the biogeochemistry of aqueous and sedimentary environments, particularly organic matter and trace metal cycling.
The senior personnel, located at UM or Bigelow Lab, in this program are as follows:

**Dr. Robert Steneck** is a specialist in the productivity of seaweeds and their incorporation into food chains. He is particularly interested in the use of respirometry and grazing studies to measure algal community metabolism. Seaweeds are very significant in the overall photosynthetic production of organic materials in Maine coastal waters, more so than most U.S. coastal areas. Dr. Steneck is involved in the determination of spatial and temporal patterns of production of debris from seaweeds. This debris forms a major and distinctive type of organic contribution to the sediments, and therefore is likely to influence strongly both the patterns and extent of sediment metabolism and fisheries production. UM

**Dr. Les Watling** is a benthic ecologist with a primary focus on the factors that control the structure of sediment-dwelling animal communities. He is primarily responsible for the microscopic identification of food particle types in sediments and their relationships to the animals that feed upon them. He is developing new parameters with which to characterize these particle types using several types of microscopy. He is also involved in the enumeration and identification of animal communities at sites being studied by the more chemically-oriented staff, using multivariate statistical techniques to discern relationships between biological and chemical parameters. UM

**Dr. Lawrence Mayer** is concerned with organic and inorganic chemical aspects of sediments. His role is to provide chemical identification of the origin and quality of organic matter in sediments, using a variety of chemical (organic/inorganic) and isotopic techniques. He also relates organic matter accumulation and subsequent sediment metabolic responses to various inorganic aspects of the sediments, such as the constituent minerals and their metal oxide coatings. UM

**Dr. Leon Cammen** is a specialist in the study of carbon flow through sedimentary ecosystems. His particular interests lie in the partitioning of organic resources among sediment animals, bacteria, and the sediment itself. He approaches this problem by combining experimental investigations of organic carbon utilization by animals, using isotopic techniques, with field data of carbon pool sizes in various biotic compartments. He interprets these data using numerical models of carbon flow. BL

**Dr. Gary King** is a microbial ecologist who provides the group with expertise in the fundamental role that bacteria play in sediment biogeochemistry. His specific interests are in assessing rates of decomposition in the sediments and types of metabolic pathways involved, particularly as they are affected by input of various types of organic matter. These factors are measured by examining pool sizes of various metabolites and their rates of production or disappearance using chemical and isotopic techniques. UM

**Dr. John Christensen** is a biogeochemist who specializes in production of nutrients in the sediments and their return to the water column. He is particularly interested in the role of sediment-dwelling animals in enhancing this return flux. His approach to these problems is to combine field measurements of pool sizes and production rates with flux measurements of materials out of the sediments, using numerical modeling techniques to deduce mechanisms of solute movement. BL

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**In the field of research**

A doctoral candidate who looks like a quintessential sea captain, holds a U.S. Coast Guard Captain’s license, is a licensed airplane pilot and a certified underwater instructor, has directed projects for the Smithsonian Institution, and whose vita includes a year out of nowhere spent driving a cab in New York City, is one of the more colorful field researchers found involved in University of Maine marine studies. Craig Shipp is at UM because it’s the only state university with the proper side-scan and other equipment on-line to continue a study of Gouldsboro Bay, begun under the auspices of the Smithsonian and for which funding was pulled. Shipp is just one of the graduate students, field crew, and research associates who contribute to the enriching and optimistic ambience surrounding marine research at the University of Maine.

Three days spent on site last summer at Great Spruce and Spruce Islands with Professor Sanger and his field crew reaffirmed a deep respect for academia and research: while the crew spent the days working on the digs, and in one case digging on Roque Island as a follow-up to an earlier superficial geological survey, the evening hours were spent pursuing parallel interests. Doug was studying mycology and produced a Chanterelle and King Bolete, both of which were carefully studied, sauteed and consumed. David had rescued a small raptor, a kestrel, and had brought it along to camp to tend; Peter spent the evening organizing field notes for Steve, research technician and field director for the project; Lew missed his family and wanted to spend more time with his children, but soon immersed himself in reading Indian Life on the Upper Missouri; Bill was preparing for the next day’s trenching out on the large Great Spruce shell midden, and Patrick, the project leader’s son, had just joined the group for his fifth summer working on his father’s digs, a summer activity he began at 14. The atmosphere was mellow; information was exchanged, mulled and sometimes gently corrected.
A JOURNAL OF RESEARCH
AT THE UNIVERSITY OF MAINE AT ORONO